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ABBREVIATIONS

A.R.C.	Agricultural Research Council
A.L.D.	Average Lethal Dose
Antu	α-naphthylthiourea
B.S.	British Standard
B.S.I.	British Standards Institute
B.S.T.	British Summer Time (G.M.T. + 1 hr.)
D.B.S.T.	Double British Summer Time
L.A.	Local Authority
L.D.	Lethal Dose
M.A.F.	Ministry of Agriculture and Fisheries
M.O.F.	Ministry of Food
M.O.H.	Medical Officer of Health
M.O.S.	Ministry of Supply
P3	Protected Poison Point
P.L.H.A.	Port of London Health Authority
R.C.T.	Rat Control Test
S.A.L.A.M.	Société Anonyme Levant-Africaine Méditerranée
W.A.E.C.	War Agricultural Executive Committee

5

THE REACTION OF THE BROWN RAT TOWARDS CHANGES IN ITS ENVIRONMENT

By MONICA SHORTEN (MRS. A. VIZOSO)

I. INTRODUCTION

(*a*) **General remarks**

RATS are commonly credited with great cunning, and failures to poison or trap them are attributed to their powers of recognizing harmful objects. As will be shown in the present chapter, brown rats have a natural form of behaviour which often enables them to avoid destruction, but which is also displayed towards many objects which can have no possible association with danger. In the course of our own work this behaviour was first encountered by Ranson during the design of P3 (a special container described in Ch. 3), since rats seldom entered and took poison baits until after a lag of some days. Soon afterwards Chitty found that rats also showed an initial avoidance of harmless objects such as pieces of wood or metal placed in their environment and undertook many of the studies described below.

There is comparatively little evidence in the literature that this avoidance has been recognized as part of the biological make-up of wild rats though Doty (1938) observed that in the canefields of Hawaii 'many rats are suspicious of any newly discovered food supply and nibble at or entirely refuse to eat it for 2 or 3 days'. Probably the earliest record of rats' suspicion is given by Smith (1768) in describing methods of live trapping and poisoning. (As far as is known, this author is the first to have published a work on rats after the introduction of the brown rat, *R. norvegicus*, into Great Britain). On leaving traps open before setting, he writes: '. . . the rats have free liberty to go in and out at pleasure . . . in order to embolden them before you set traps in earnest to take them . . .'; and again, '. . . with one trap only you are obliged to move your trap about, which makes them shy. . . .' '. . . I have known them to eat the food prepared for them from their holes quite up to the trap for a week before they would enter in.' The writer also appreciated that the rat may be suspicious of a new food offered to it: 'first give them some [bait] without the nux vomica figs for two or three succeeding nights, and when they find it agrees with them, they will eat that mixed with the fig with greater freedom and greediness.'

After the recognition of this type of behaviour as normal it was evident that several days should be allowed after the placing of a new object such as a bait container before expecting rats to approach it; secondly, it strengthened the decision to employ prebaiting before poisoning or trapping. Apart from these practical applications a problem of great biological interest was obviously involved, to which a good deal of study was devoted for its own sake. In addition, many accidental discoveries resulted from our field experience before the extraordinary sensitiveness of wild rats to many forms of environmental change was fully realized. We have used the term 'new object reaction' to describe this suspicious behaviour. Although the rat may react in the same way to changes other than the actual introduction into the habitat of new objects, the reaction was first noticed by us under these conditions, and the term has been retained as a convenient label, although it is not completely satisfactory.

The other types of change observed to produce this reaction in the rat were: moving familiar objects to new positions, replacing of one object with another almost identical one, alteration in the position of the food site, changes of food, and even simple changes in the habitat such as sweeping up a dirty floor. All these cause a change in behaviour until the rats accustom themselves to the new situation.

This natural suspicion of the brown rat towards anything unusual in its surroundings was reflected in many of the experiments by a decrease in the amount of bait eaten on the night after the disturbance, compared with normal feeding. When watching was carried out, the behaviour of individual rats confirmed the view that this slackening in feeding was due to suspicion; and it was discovered that changes in the environment could be appreciated at night. More recently Southern, Watson, and Chitty (1946), using infra-red radiation, found that new objects were apparently not discovered at such a great distance in darkness as they were in light.

Although most of the changes causing the reaction were spatial in nature, changes in lighting also produced alteration in behaviour, but in a less striking manner.

It is first necessary to dispose of the suggestion that the reason for the suspicion of the rat towards new objects placed in the environment is human odour caused by the handling of the objects by man. Venables carried out an experiment in which two series of tunnels were used, one freshly treated with human saliva and well handled each time before baiting; the other scrubbed, rubbed well with horse, cow, or pig dung, and handled only with aniseed-soaked gloves. Entrances and bait-takings were recorded for both sets of tunnels, and it was found that there were seventy-three entries into tunnels with human odour, and seventy-six into the tunnels without it. Boulenger (1920) describes a similar experiment. Ten gin traps and ten nipper traps, half of which were handled freely, and half with gloves after being rubbed in earth and faintly scented with aniseed, were set in a rat infested locality. As a result, thirty-six rats were found in those traps which had been handled in the ordinary way, compared with thirty-one in those handled in gloves.

These experiments, showing that in the course of several days rats approached equally well objects which had and had not been handled with bare hands are not quite the same as demonstrating complete avoidance of an untouched object. One such example was the refusal of rats to cross a trail of plaster of Paris freshly shaken out of a tin; and there have been other cases where the amount of handling was negligible. Moreover, since in the majority of environments many objects, including food, are frequently handled, it is difficult to believe that human odour is a cause of alarm.

(*b*) Deterrents

It would not be surprising if it were found that a degree of new object reaction could be caused among rats through the sense of smell. Thus the introduction into the environment of substances with odours strange to the rats might discourage them from indulging in their usual activities for some time. Very little information of a precise nature has been gathered on this aspect. However, the literature on repellents contains many recommendations of such chemical deterrents as powdered sulphur, lime, lye, copperas, creosote, carbolic acid, kerosene, and oils of peppermint and wintergreen (Brians, 1938). The question arises whether the effect, if any, of these substances is due to their 'newness' in the environment, or to their intrinsic unpleasantness to the rat.

Ford and Clausen (1941) discuss the use of *n*-butyl mercaptan, the active ingredient of the odour of skunk. White rats faced with food treated with the volatile substance refused to eat until the odour had disappeared; they appeared excited, and the hair rose on their backs. Rats on a farm refused, for 4 months, to touch food smeared with a mixture of honey and mercaptan. Rats on a city dump ate the treated food after 3 days. Here the food supply was limited and the number of rats large; it is also suggested that the rats here may have been conditioned to the odour of mercaptans from decaying organic materials. The effect observed in these tests may have been due to a dislike of the associations evoked by the odour, or of the odour *per se*, rather than new object reaction towards an unfamiliar factor in the environment.

There are some superstitions about rat repellents which may have had as their original basis an observed new object reaction. Thus the belief that a deer skin laid on the floor will keep off rats (Anon., 1777) may have arisen because on some occasion when this was done a new object reaction kept the rats away. A circle of sawdust, 6 in. wide, sprinkled with creosote, has also been recommended to keep rats from attacking stacked foodstuffs.

The duration of the effect of these chemical deterrents, which appear to operate through the sense of smell, seems to be the most hopeful index to their nature: whether they are distressing to the rat or are treated with suspicion because they are novel. If the first alternative is operating, one would expect the effect to last until the odour was removed or ceased to be potent. If the second suggestion is the right one, then it would be expected that the rats would overcome their suspicion in time, and cease to be kept back by the deterrent.

Tests where the efficiency of a chemical deterrent is checked by treating food with the substance, and noting the reactions of rats towards it, suffer from the objection that sampling may take place, and the food be found to be unpalatable. The deterrent should be tested in a position between the rat and his food. Our only experiences with strongly flavoured substances are with aniseed and zinc phosphide, neither of which have been observed to produce new object reaction of importance.

2. SENSES OF THE BROWN RAT

A better understanding of 'new object reaction' would be reached if two questions, beyond the scope of the work done by the Bureau during the war, were answered. Why does the rat react to a new object as it does? (Why is suspicion and alteration in behaviour caused by such a harmless new object as a torn-up piece of card?) Secondly, by what senses is the presence of such an object revealed to the rat? New objects are appreciated and avoided by the rat at night; and although it is not known how well brown rats can see in the dark, this suggests that some sense other than sight is at work here. In the light, the suspicion of the rat becomes plain to an observer while it is still far from the object.

Carr (1917) and Vincent (1913) state that the vibrissae, or tactile hairs on the snout, act as distance receptors for the white rat, indicating to it the proximity of objects, the position of edges and corners, any inequalities in the surface, and aiding equilibrium. They are a valuable supplement to poor vision. Carr states: 'The removal of stimuli is without effect, while the introduction of novel stimuli operates as a disturbance.'

We have often observed that a rat about to enter a habitual feeding place will, if suspicious, stay at the entrance hole and lift the snout high in the air, turning the head from side to side. It is not certain whether olfactory testing is going on, or whether the vibrissae can appreciate objects far beyond their reach. The olfactory part of the rat's brain is very well developed.

Carr and Watson (1908) in the course of maze experiments with white rats, found that sight is apparently not used as a guide in a well-learnt maze. They used both blind and normal rats, and found that when a runway in the maze was shortened in length, the rats ran into the end wall at full speed instead of making the correct turn. When the runway was extended in length beyond the distance learnt by the rats, they were found to turn and run against the wall of the runway at the exact spot where the turning had previously been. Again, there was no significant difference in the behaviour of the blind and normal rats.

The authors suggest as an explanation of this phenomenon that where a maze has been learnt (i.e. when a habit of movement has been formed), each move is determined by the sensations caused in the previous move.

Thus, if a false move is taken, the rat is often observed to retrace its steps as if to pick up a cue that it has lost. Dennis (1929) gives an account of rats, conditioned to running around partitions, which continued to show traces of this behaviour up to five days after the partitions had been removed. Blind white rats with the vibrissae removed were used for this experiment.

It is difficult to decide how much of the data relating to experiments of this nature can be applied to the brown rat (and no further abstracts from this vast literature can be attempted here). It is known that the two races differ in their approach to a new object. The fact that a white rat will evince curiosity and soon explore any new object placed in its range warns us not to argue too closely from one to the other.

It is thus only possible to theorize: that some combination of the olfactory sense and information gained through the vibrissae, with aid perhaps from visual data, warn the rat that there is a change in the make-up of the usual environment. This change brings about an alteration in behaviour, varying in strength and duration with the cause. The alteration may be due to a confusion in the accustomed sequence of sensations directing the rats' behaviour. After a time the rat may adjust itself to the new situation, and carry out a modified, or in some cases, the same, pattern of behaviour.

Cases have been recorded by us of rats running right up to a new object, then stopping dead and retracing their steps. This agrees with the phenomena observed by Carr and Watson; although in the case of the wild brown species, the effect may be not a repetition of the action, but a refusal to attempt it again. Whereas the white rats in the experiments quoted did not appear to notice the alteration in their surroundings until face to face with it, the brown rat sometimes appears to appreciate changes from a distance.

The first question posed in this section is more a matter for the psychologist. It is impossible to attempt to answer it on the evidence we have collected.

3. FACTORS CAUSING 'NEW OBJECT REACTION'

(*a*) Methods of observation

There are five different ways in which one can estimate the effect on rats of changes in their environment. (*a*) Direct observation gives the most complete information, and is now practicable in complete darkness (Southern, Watson, and Chitty, 1946). Data on individuals are obtained by this method whereas the others only show the effect on the population as a whole. (*b*) The apparatus described by Chitty and Shorten (1946) and in Chapter 4 can be used to record speed of feeding before and after a change in the environment. (*c*) Comparison of the total daily takes of bait will reflect changes due to disturbance but will not show the time when they operated most strongly or the duration of the effect. Moreover, the rats may overcome their suspicion of small changes during the night and make up for lost time by an increased amount of feeding later on. (*d*) Patches of plaster of Paris may be placed to show tracks, but should be established some time before the experiment, as rats have been known to avoid the powder itself. A comparison of activity at normal times and in the presence of some disturbing factor can then be made. This method suffers from the fact that it is difficult to get any exact measurement of activity; gross differences may be observed, but it is impossible to estimate the numbers of rats making the tracks and no clear idea can be gained of the sequence of events. Thus Venables found little difference according to height in the number of tunnels entered, whereas other experiments by methods (*a*) and (*c*) showed a definitely greater avoidance of the lower tunnels. (*e*) The reaction to poison baits under familiar and changed environmental conditions is also a guide to the speed of feeding: in the latter case the intake of poison may be so reduced that it fails to kill the rats. As a rule, however, comparative observations cannot be made on the same population.

(*b*) New objects near a food supply

New object reactions have been recorded to such varied objects as planks of wood, pieces of metal, a torn-up filing card in a sewer, patches of plaster of Paris, tin cans, a dustpan, a sheet of uralite, and half a loaf of bread. An experiment already described (Chitty and Shorten, 1946) serves to illustrate the type of change that is seen in the behaviour of a rat in the presence of a new object. Rats at the wild experimental colony (Chapter 4) were accustomed to feed inside a shed, most of them coming in through the same hole and going straight up to the food, though some hesitated on the way. The record in Table 1 was made by an observer hidden in a special compartment overlooking the lighted stage where the rats fed. A control disturbance was made before the normal activity was recorded for comparison with that after the placing of a piece of wood on the stage. It was found that the rats quickly recovered from the control disturbance, but that the piece of wood entirely stopped their feeding for the 40 minutes it was in position (between squares *B* and *C* in Ch. 4, Fig. 2).

TABLE 1. *Effect of a piece of wood upon the number of passages (counted in one direction only). Artificial light, 5 June 1941*

Time (D.B.S.T.)	*Visits to food*	*Part-way visits*	*Visits elsewhere*
8.15	Control disturbance		. .
8.30–36 . . .	48	13	0
8.40	Piece of wood placed		. .
9.00–06 . . .	0	6	3
–12 . . .	0	5	0
–18 . . .	0	7	7
9.20	Piece of wood removed		. .
9.40–46 . . .	48	14	0

In another experiment, data from the total night's take were supplemented by half-hourly records of feeding rate from the food-recording machine. The experiment was done in darkness, some new object being placed on each of five consecutive nights. Except on the first night these were in the direct path of the rats coming from the entrance hole to the hopper to feed, and Table 2 shows the main effects of these new objects.

TABLE 2. *The effect of new object reaction on the take of wheat*

Feb. 1943	*Objects placed*	*Takes of wheat (g.)*		*Ratio of takes before and after midnight*	*Total in 24 hr. (g.)*
		6 p.m.–12	*12–6 a.m.*		
5/6	Build-up after token baiting	190	119	1.6	448
6/7	,,	190	164	1.2	466
7/8	,,	317	157	2.0	586
8/9	,,	246	168	1.5	496
9/10	,,	213	246	0.9	511
10/11	Tin can	134	146	0.9	388
11/12	Another tin can and a dustpan added	49	75	0.6	160
12/13	Iron strip added	41	90	0.5	250
13/14	Boards added	82	146	0.6	358
14/15	Baking pans added	63	175	0.4	366
15/16	No change	254	131	1.9	582
16/17	All removed	Records spoiled			671
17/18	None	284	179	1.6	701
18/19	Three glass jars	198	157	1.3	545
19/20	None; jars removed	302	187	1.6	735
20/21	None	302	119	2.5	817
21/22	,,	276	172	1.6	660
22/23	,,	250	146	1.7	869

Total feeding was depressed on each night but the effect was far more pronounced before midnight than in the 6 hours after, the relative importance of these two periods being reversed. From 12 to 3 a.m. new object reaction had apparently been overcome since the amounts taken were about the same as before and after the disturbing factors were present. However, it seems more likely that this was due to part of the population eating more rapidly than usual, because of hunger; or the inclusion of an extra feeding period because of a change in rhythm. The takes, from 3 to 6 a.m. and therefore for the whole period 12 to 6 a.m., remained on the average lower than usual. If new object reaction had been entirely overcome, these takes would probably have been greater than normal because of hunger resulting from slow feeding early in the night.

On the sixth night, when the objects were left in position unchanged, feeding was much more rapid before midnight, and the total take was about the same as that before the objects were placed. When they were entirely removed, however, the take immediately rose to a much higher level. Later, three glass jars caused only a slight reaction, after which there were several days of generally high takes.

In these two experiments the behaviour of the rats reverted to normal very soon after the disturbing factor had been removed. In the watching experiment in Table 1, the rats were behaving normally 20 minutes after the removal of the new object; and in the second experiment (Table 2) feeding quickly reached a high level. This rapid recovery is general, though longer delays have been known.

In time most rats lose their suspicion of the 'new' object, and a return to normal behaviour can be observed in its presence. In the second experiment quoted above, this adaptation to the new situation is expressed both in the total amount of feeding for each night and in the amount of feeding recorded for the different periods of each night. On the first night of placing a new object there was not a pronounced drop in the night's take; probably because the new object was not placed in the direct path of the rats going to the food. On the next night it was so placed, and another new object was added. The take dropped considerably. On each of the next 3 nights a new object was added, and the take remained sub-normal, but a gradual rise was observed. The food affected was the main source for these rats, and it is reasonable to suppose that cumulative hunger was acting against the new object reaction to some degree. On the next night there was no change in the objects, and feeding reached a slightly higher total than that observed before the experiment started. This suggests that the rats had overcome their suspicion of the objects already in position by then. When the objects were removed the amount of food taken increased well beyond the level observed before the experiment, was depressed by the placing of the jars, and recovered immediately they were removed.

New object reaction has been shown towards an object similar in appearance to one which has been a feature of the environment for a long time; even when the new object is placed in exactly the same position as the old one. There were 5 days' complete avoidance of a P3 which had been substituted for an apparently similar one at the same site, the only major difference visible in the two containers being that the new one had two small holes drilled in the top and in the baffle.

A similar example occurred with pipes, one of which was used so much more than the other three that it became difficult to provide it with a surplus. Accordingly another pipe, open at both ends, was placed in the same position as the original, which was moved back, thus giving double the capacity. At the same time two other pipes were added alongside. In addition to that in the pipes, wheat was also available elsewhere in the shed. The effect of adding the extension to the most popular pipe was a complete refusal the first day, followed by very low takes for the remaining 4 days of the experiment. Instead, some rats shifted their attention to the other pipes, including those in the new positions (Table 3). Other rats evidently shied away from the new pipe arrangement, and fed from the pile of wheat farther inside the shed where the take went up to 57% of the total, from an average of 35% for the previous 4 days.

TABLE 3. *Drop in wheat take caused by the addition of extension pipe*

Aug. 1941:	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
Source of wheat											
Popular pipe . .	880	830	980	1,000	..	..	..	..	..	..	..
Popular pipe + extension . . .	..	..	..	..	0	95	80	90	130	..	..
Other original pipes .	780	950	1,007	610	1,245	1,430	1,055	1,240	995	..	..
Two new pipes .	..	..	..	..	140	220	252	430	635	..	..
Total (all pipes) .	1,660	1,780	1,987	1,610	1,385	1,745	1,387	1,760	1,760	..	..
Floor of shed . .	950	960	1,040+	835	1,866	1,480	570	1,230	1,330	3,290	2,670
Total . . .	2,610	2,740	3,027	2,445	3,251	3,225	1,957	2,990	3,090	3,290	2,670

Similarly, in a cage test, the substitution of one identical feeding tray for another was probably why three rats starved themselves for 2 days with a loss of 25–30 g., or over 10% of their body weight. Unfortunately the new tray had been replaced 6 in. farther under cover, so that this factor may also have played a part. (There are several other instances of new object reactions to which more than one change may have contributed and which for simplicity are not quoted in this paper.)

(*c*) Food in newly placed containers

When food is placed in a container newly introduced into the environment, a display of new object reaction results. This fact and its importance in the control of rats in the field will be discussed in a following section: some examples of the phenomenon will be given here.

Rats at the experimental colony at a time of food shortage had been accustomed to feed on wheat during the day-time from the floor of a shed. An observer who had watched the feeding under normal conditions also recorded the effect on the rats when the wheat was placed in a shallow metal tray in the same position on the floor. All feeding ceased at once, and 3¾ hours later still none had been taken. The next day all the wheat had been taken from the tray, and though the rate of feeding was not observed in this period, it might have been expected to be slower than usual in its initial phase. (Uncertainty about when new object reaction will be overcome prevents direct observation of this early stage; and the food-recording machine does not distinguish between slow feeding by many individuals and normal or rapid feeding by a few.) It will be seen from Table 4 (quoted from Chitty and Shorten, 1946) that even the number of inspections of the food in the tray decreased during the watching period. This same tray was avoided for an even longer time in a sewer. After an initial period, during which at least 200 g. wheat had been taken from the ledge, none was taken from the tray during the next 13 days although rats were seen close to it.

The rats at the experimental colony were at another time confronted with wheat placed in two shallow metal baking pans, after feeding from the same food off the floor. The consumption for the night of the change dropped by more than 90% as a result, but recovered immediately afterwards (Table 5; Ch. 4, Fig. 10).

TABLE 4. *Effect of a newly placed container upon the number of passages (counted in one direction only). Daylight, 24 December 1943*

Time	*Part-way visits*	*Mouthfuls of wheat*	*Steady feeding*	
11.10 . . .	Control interruption			
11.13–15 . . .	0	5	0	
–20 . . .	3	36	0	
–25 . . .	0	61	2	
–30 . . .	2	55	3	
Total . . .	5	157	5	162 feeding visits; 80 g. taken
	Wheat placed in tray			
–11.35 . . .	26	0	0	
–40 . . .	6	0	0	
–45 . . .	44	0	0	
–50 . . .	42	0	0	
–55 . . .	32	0	0	
–12.00 . . .	16	0	0	
–05 . . .	21	0	0	
–10 . . .	14*	0	0	
–15 . . .	12	0	0	
Total . . .	213	0	0	no feeding visits

* One rat came within 2 in. of the tray.

TABLE 5. *Effect of placing food in trays*

Day:	*1*	*2*	3	4	5	6
	on floor		in trays			
Take of wheat (g.) .	1,895	1,800	160	1,640	1,927 - - - 1,928 (av.)	

(*d*) Moving a familiar object

Experiments have demonstrated that the displacing of an object already familiar to the rat may cause a reaction similar to that observed when a new object is placed in the environment. The reaction to the moving of a familiar object has been observed to be of shorter duration and less strength. The fact that a reaction is shown suggests that the rat is disturbed by a change in spatial arrangement within the habitat, and not by simple fear of the object.

Thus a population of rats baited at a P3 twice showed a drop in the total night's take when the P3 was replaced 1 ft. away from its normal position

(Table 6). The second occasion (*b*) followed immediately upon a partial reduction in numbers:

TABLE 6. *Effect of moving a feeding station*

Day:		*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
Position:		Normal				1 ft. away	Normal					
Take of wheat (g.)	(*a*)	250	322 - - - 323		500+	150	400	425	465 - - - 465 - - - 465 (av.)			..
	(*b*)	..	90	182 - - - 183		20	165	140	55	145	250	..

At the experimental colony a population of rats was accustomed to feed on wheat from a hopper placed against one wall. The behaviour of the rats was watched for a short time, and the feeding throughout the night was recorded. When the hopper was moved against another wall, about the same distance from the main entrance hole, there was an hour's delay in the start of feeding compared with the previous night, but the rate of consumption of the first 300 g., and the total take, showed quick adaptation to the normal. During a short watch a large rat was observed to go twice to the original position of the hopper and sniff. It then approached the hopper in its new position, exhibiting the greatest caution, and retreated rapidly, though there were several other rats feeding from it. A similar reluctance to imitate was observed on other occasions. Thus only a few rats went through or round a new patch of plaster of Paris, others stayed well away from it and feeding remained abnormally slow for 1½ hours.

Other populations have contained a proportion of rats that would come out for token baits in the afternoon, while their fellows refused to move out from cover. These 'bolder' rats were frequently attacked on their return from the wheat, the younger ones sometimes being thrown over on their backs, and the wheat removed into the jaws of their assailants.

In designing the food-recording apparatus the possibility of one type of new object reaction was taken into account, but not that now to be discussed. According to the size of the population or the amount of wheat provided, pipes of 1 to 4 in. diameter are used to deliver the wheat; but a change of pipes during an experiment is not observable except at the top of the apparatus, 18 in. above ground level (Ch. 4, Fig. 1). New object reactions did occur after a change of pipes, but not because of their difference in size; for it was discovered later that the removal of the apparatus and its replacement even with the same pipes had a pronounced effect on the rats. Thus on 2 consecutive days the apparatus was removed for 1 hour and put back apparently as before. Yet feeding completely ceased for 48 hours, and was only resumed slowly the third night. Table 7 shows when feeding started and the time at which an arbitrary amount of wheat had been eaten on this and the following 2 days. There is a marked difference in the strength of reaction in this case and in that previously quoted, where the position of the hopper was changed (but different populations of rats were involved). The last column shows a second, less pronounced new object reaction, this time due to disturbance in changing to the 2-in. pipe for token baiting. Later on, the change back to a 4-in. pipe did not affect the rats since this was done without removing the apparatus to drain out uneaten wheat.

TABLE 7. *Effect of new object reaction on time of starting, initial speed of feeding and total take of wheat*

Date (Dec. 41–Jan. 42):	*31/1*	*1/2*	*2/3*	*3/4*	*4/5*	*5/6*	*6/7*	*7/8*
Start of feeding (p.m.)	8.22	6.38	6.15	6.18	6.06	6.20	6.00	6.45
240 g. finished .	4.00 a.m.	7.45 p.m.	8.15	7.15	7.30	7.30	7.00	10.40
Wheat take in 24 hours (g.) .	458	1,507	1,704	1,919	1,790	1,630	1,814	500+

(*e*) Reaction to new food

The suspicion of the rat towards a new food is strongly reminiscent of new object reaction and its importance in field work has been pointed out by Doty (1938) in the passage already quoted. Some notes by Ranson on the effect of placing half a loaf of white bread on the approach to a supply of wheat read as follows:

> In the previous 10 min. 39 rat visits to the wheat pile had been observed; but after bread had been placed, although a number of rats entered the shed, they nearly all turned back. Only one rat, in fact, seriously attempted to pass the bread. It first crept up behind and showing great hesitation, attempted to get between the loaf and the wall. After two attempts, which brought it level with the loaf, it gave up and went round to the other side. Here there was plenty of floor space for it to keep well away from the loaf, but after again getting level with it the rat went back and out of the shed.

When a familiar food is replaced by a new one at the same site there is evidently a similar type of reaction. As shown in Chapter 7 rats eat approximately the same daily amount of sugar-meal as wheat but there is often a period of reduced feeding after the change from wheat. Similar effects may occur when the food is changed from wheat to 1:1 rusk, the takes on the first one or two nights being lower than on the succeeding nights (although actually greater than the previous wheat takes because of the greater water content). With bread mash the take by fully prebaited rats is about 3 times that of wheat but this ratio is not always reached during the first 2 days after the change (though in many cases, with this and other baits, there is no apparent avoidance on the first night). However, it should be remembered that in experiments where the total night's take is the index of the reaction, the effect is perhaps masked by the inclusion of feeding later on in the night when some rats may have overcome their hesitation towards the new food, and may be feeding rapidly because more hungry by then. Table 8 shows what happened when nine rats, accustomed to feeding on wheat in a metal tray at one side of their outdoor cage, were given a new, identical tray, on the other side, containing rusk. As there was no take at all from the new food on the first night, the contents of the trays were switched around so that the rats were confronted with their accustomed food in a new site and a new container, and a strange food in the usual feeding place. The rats ate their full requirements from the old site, thus preferring a change of food to the change of site and new container. The next night the contents of the trays were again changed, and again the new site was avoided.

TABLE 8. *Refusal of caged rats to change their feeding site*

Day:	*1*	*2*	*3*
Take of wheat (g.)	260	0*	265
Take of 1 : 1 rusk (g.)	0*	535	0*

* Food in new container at new site.

Some direct observations have been made on rats confronted with a new food at an established feeding point. A population which had been token-baited on wheat for some days was given 500 g. wheat at 11.55 a.m. In the first 5 minutes of watching about 40 feeding visits were observed, in the next 5 minutes there were 78, and in 30 minutes from the start of feeding 255 g. wheat had been taken. This rate was fairly typical of that on previous days. For the next half-hour, sugar-meal was substituted for the wheat, and the rats were observed to show hesitation and suspicion. In the first 10 minutes only 7 feeding visits were made, and 5 inspections of the food pile. At the end of 30 minutes there had been 66 inspections but only 24 feeding visits and the take was too small to measure. The feeding visits were mostly by 2 rats; before, 13 rats had been observed feeding on the wheat at the same time.

The next day the food was again changed; this time to 1 : 1 rusk. Feeding started on this at once, and although some hesitation was noted, 170 g. had been taken in the first half-hour (Ch. 4, Table 34). There was a daily increase in the speed of feeding up to about twice that on wheat, and then when wheat was again provided it was eaten more slowly than usual (it is not certain, however, that this latter drop is significant).

A study of marked rats (Ch. 4, Appendix 2) showed that there are great individual differences in reaction to a new food. The following extracts illustrate this point. On the first night of a change from wheat to rusk, rat No. 9, a 240-g. ♂, took one mouthful only at 7.30 p.m. and was seen no more until 11.00 p.m. On the next night it was seen once only but on the third night it fed well on poisoned rusk. Rat No. 10, a 300-g. ♀, on all nights except one, fed most rapidly on wheat within the first 15 minutes of starting. On the first night that rusk was substituted for wheat, it fed only once in the first 4 hours, on the second night its feeding was spread over several periods and the peak rate was reached during the third hour. Rat No. 3, a 290-g. ♂, fed on wheat for at least half an hour without any long breaks, once it started. On the first night of rusk it was more intermittent in behaviour. Three rats, however, were observed to take to rusk well: No. 5 four times paid seventeen visits per 5-minute period to the new food on the first night. (All these rats had last been baited with rusk 6 weeks before.)

(*f*) Changes in illumination

Changes in illumination at a site normally used for food suggest that this has less effect on the behaviour of the rat than the placing of a new object. In the most rigorous of several tests on this factor, records of the total night's feeding were obtained for a period during which the lighting varied from none to 6 and 24 watts (Table 9). Records of speed of feeding throughout the nights showed that the dim light had no effect on the feeding rate, since each curve was within the range of normal variation for the period 6 p.m.–9 a.m. However, when the strong light was on, the average weight of wheat eaten in 24 hours was about 10% lower than it was with the dim light or in darkness. Again, however, the variation from hour to hour was well within the normal and the 10% difference in total take is probably not significant.

TABLE 9. *Effect of artificial light on total take of wheat in 24 hours*

Day	*Feeding in darkness: take (g.)*	*Day*	*Feeding in dim light: take (g.)*	*Day*	*Feeding in bright light: take (g.)*
1	1,150	5	1,150	7	970
2	1,100	6	1,090	9	1,060
3	1,030	8	1,210		
4	1,240				
Av.	1,130		Av. 1,150		Av. 1,015

In many other cases at the experimental colony the switching on or off of the lights did not cause cessation of feeding or any noticeable reaction amongst the rats, and there are only two instances to the contrary. Both concern rats which had not been conditioned to feeding under illumination and therefore resemble the behaviour commonly noticed in the wild or in outdoor cages when a light is suddenly switched on at night. After a period of nightly feeding in darkness, all the rats ran away from the food when the lights were again switched on, leaving the shed with explosive violence. In another case, at the start of conditioning, the rats were obviously shy and the lights were turned off for 5 minutes. Feeding was heard in the darkness and two or three small rats ran away when the lights were again switched on. A large rat was also seen to run away; when it returned later it took only occasional mouthfuls, instead of feeding continuously as it had been heard doing before.

Thus although changes from complete darkness to dim lighting, and variations in its intensity may sometimes disturb the normal feeding behaviour of the rat, the effect did not prove very great at the experimental colony and was quickly overcome. We have also found rats to return immediately after the release of a flashlight bulb in a dimly lit shed.

These experiments on the effect of illumination took place among a colony of rats which had no important supplies of alternative food available. Reaction to changes in illumination might have been greater and of longer duration in a habitat such as farm buildings, where the rats might have had access to other food in the dark.

(*g*) Noise

It is not surprising that an animal like the brown rat, which is constantly observed to exhibit great suspicion and alertness towards unfamiliar factors in its surroundings, should be disturbed by noise. This characteristic is probably common to all wild animals; although the rat, because of its almost invariable choice of a habitat close to man, is often surrounded by the noises of his activity. Rats have been observed in factories, steelworks, railway depots, and other noisy environments, foraging in the day-time. The slight experimental data which we have collected is not sufficient to determine whether rats can become conditioned to noises which are part of the habitual surroundings, in the same way that, after a sufficient lapse of time, they accept new objects which at first alarmed them. On the whole it seems that the disturbing effect of noise remains operative in such cases, but that the rats recover more quickly.

Rats living in a basement of a shop were disturbed while feeding by the noise of a loose grating in the street above, which was heard every time a passer-by stepped on it. Although this noise must have been constantly heard in the day-time and evening throughout the life of the rats concerned, it was observed, while watching, that the rats left the food and ran to cover each time. They returned and fed normally in under a minute on most occasions. This case appears to bear out the suggestion that an accustomed noise is not a deeply disturbing factor to the rat.

The rats at the experimental colony often exhibited no marked reaction towards the noise of rain beating on the tin roof of the shed where they were feeding, or to the noise of trains passing on the lines immediately behind the shed. The noise of other rats fighting and moving about in the next-door room, and the noise of the observers talking did not cause any significant alteration in behaviour. When a sudden, unusually loud or unfamiliar noise was heard, however, the rats were observed to run from the food and remain under cover for periods of up to 5–10 minutes.

A reasonable assumption would be that rats are not much disturbed by noises which maintain an accustomed tempo, forming a typical aspect of the surroundings; but noises which occur often, but at irregular intervals and with varying intensity and duration, retain the power to disturb the rats. Vibration accompanying the noise is likely to add to the disturbing effect. It has been suggested that rats are not much disturbed by a sound such as a note from a wind instrument; whereas they react to the same sound from a string instrument, or any other which involves an accompanying grating or percussion. Much the same reaction is seen when the incidental noises alone are produced, as when the sound itself is made along with them. This would perhaps explain why so little reaction was observed towards the talking of the observers at the experimental colony during watching.

It was noticed that after a poisoning experiment at the experimental colony the rats were markedly nervous and suspicious of noises that they might normally have been expected to ignore. This phenomenon points to a higher degree of alertness arising out of an unpleasant experience (a similar quickening of suspicion to that in white rats towards plain food, after small doses of poison (Ch. 8)).

(*h*) General changes in the environment

A general alteration to an environment, such as cleaning a floor, tidying up of material that the rats are using as cover, or any other measure of this nature, has been observed to result in a display of new object reaction. This might be expected after the various types of disturbing factors noted above have been studied. Material that has been used for cover by the rats may operate in forming a pattern of movement that is completely disrupted when the environment is disturbed.

(*i*) Removing a new object

It appears that the removal of a disturbing factor from the environment does not, in itself, bring about a further reaction. The pattern of movement induced by the new object may, on the other hand, persist for several days after the object has been removed. Rats at the experimental colony were observed to take a circuitous route to their food after a piece of wood, which had been placed as a new object in their direct path for some weeks, was removed. Several days elapsed before the direct path was again taken. (The placing of the wood and its immediate effects are described in § 3 (*b*).) The experiment described by Dennis (1929) and quoted in § 2 also demonstrates this after-effect.

Rats at the experimental colony were conditioned to feed on wheat from the floor of the shed. No reaction was shown in the total night's take when four pipes, from which the rats had been taking some of their food, were removed. At the start of the experiment, when the pipes were first placed, a new object reaction was shown towards their presence, but this was gradually overcome, the course of events being as follows:

Some scattered wheat was placed outside the pipes, as well as a quantity inside each. On the first night, the take from the usual food source (a pile of wheat on the floor) fell to half the normal figure, almost certainly as a result of the introduction of the pipes. It was noted that a small quantity of the wheat in front of the pipes was taken on the first night, however. The following night the reaction to the pipes was largely overcome, a normal take being recorded from the usual source of food; but the pipes were not entered yet. The first entry into the pipes was recorded 9 days after they had been placed. Gradually, from this day, feeding at the pipes increased, and the take from the floor fell in proportion. Then the pipes were removed. This action must have constituted a major change in the environment for the rats, but no depression in the total take was observed; it equalled that from both the pipes and the floor on the previous night. (For a similar instance see Table 3, days 10–11.)

On another occasion a P3, placed on a well-used rat run in a barn, was avoided by the rats for a month, the run falling into disuse. Tracks were tested for with plaster of Paris, but at the end of 4 weeks none had been found. After the P3 had been removed, tracks were at once found in the run.

Numerous other examples recorded during the course of our work demonstrate that the removal of a new object, whether the rats have avoided it consistently or have partially overcome their reaction to it, does not operate as a disturbing factor of any importance.

(*j*) The effect of distance and material

It has been stated (Boulenger, 1920) that the results achieved with a wire, tunnel-shaped cage-trap (the 'Brailsford') differed according to the heights of the door and passage; and that when these were 8 in. high the largest percentage of rats was caught in the trap. The width was found to be immaterial, provided it allowed free passage for the rats. The following figures are given for the percentage of rats caught in traps of various heights: 4½ in. (19); 7 in. (28); 8 in. (34). No explanation of these percentages is given in the text.

An experiment which seems to support the view advanced by Boulenger is the following: rats accustomed to feeding in two adjacent roofless compartments were submitted to a test in which roofs of various types were placed over each in turn. Nails were driven into the wooden walls to allow heights of 4 in., 6 in., and 9·4 in. Three types of roof were used, made of wood, tin, or ½-in. wire-netting. The effect on the feeding from the food pile under the roof was recorded each day. It was found that the disturbing effect of the roof became stronger as it was lowered nearer to the food. At 9·4 in. very little effect was noted; but at 4 in. there was a definite avoidance. The roof of wire-netting had less effect than the wood or tin (Table 10), a conclusion also reached in an earlier experiment.

TABLE 10. *Effect of roofs on wheat take*

Day	*Height of roof (in.)*	*Material of roof*	*Compartment A; take (g.)*	*Compartment B; take (g.)*	*Total (g.)*
1	..	..	730	120	850
2	9·4	Tin	580*	420	1,000
3	6·0 (fell)	Board	260*	690	980
4	6·0	,,	955	150*	1,105
5	..	..	660	460	1,120
6	9·4	Board	550*	480	1,030
7	9·4	,,	..*	..	No record
8	..	..	..	..	No record
9	4·0	Board	530*	800	1,330
10	..	..	700	410	1,110
11	9·4	Tin	655*	535	1,190
12	6·0	Board	850	200*	1,050
13	..	..	770	380	1,150
14	9·4	Wire-netting	790*	370	1,160
15	9·4	,,	630	210*	840
16	6·0	,,	665*	400	1,065
17	..	..	700	500	1,200

* Indicates compartment with roof.

In January 1940 three wooden tunnels were set over separate well-marked rat runs in the snow on a rubbish dump. The entrances were 7 in. wide, and the heights were: No. 1, 7½ in.; Nos. 2 and 3, 5 in. Tunnel No. 2 had oats in it (but not on the approaches), the others were unbaited. Results were as follows: No. 1: not entered. No tracks in snow freshly dusted over the run the previous day. Rats had evidently used an established alternative trail. No. 2: no oats taken. No tracks round the tunnel. No. 3: avoided by some rats since three new trails had been established which left the main trail 3–24 in. from the tunnel and passed round it.

The suggestion that wire-netting or wire is less objectionable to the rat than wood or metal sheets is interesting. Richter and Emlen (1945) report that using a box trap of undressed wood, with no shiny parts, they succeeded in trapping seventy rats among 265 traps on the first night of placing, although the rats had been found to avoid wire and metal traps for several days or even weeks. The top of the trap was of heavy ½-in. wire-mesh hardware cloth, at a height of 9 in., though the height of the entrance was only 6 in.

Before trapping, alternative food was removed from the environment (a square city block) and the traps were baited with apple or bread, and a trail of oats, corn, and alfalfa, impregnated with molasses, was spread evenly over the floor of the trap. This was found to be an important feature of the trapping procedure. These workers observed no new object reaction to their trap, an experience contrary to our own, as in the following case, for example. A wooden trap, 12 in. deep and 15 in. wide, was set in a disused pigsty, baited with wheat and with a trail of wheat leading to the open 3-in. square door. There was no entry on the first night, although the wheat outside the trap was taken, and it was a week before the trap was completely entered.

(*k*) Alternative sources of a familiar food

There are three instances showing the effect of alternative supplies of wheat on the rate of feeding at the food-recording apparatus. Table 11 shows the relative amounts of wheat taken from the normal food source (the hopper of the apparatus) both before and after alternative supplies had been placed nearby. In each case the average feeding rate from the hopper is given for a series of days when normal surplus baiting was in progress. The figures are taken from Chitty and Shorten (1946, p. 67); but since other experiments had been interposed, feeding rates are also quoted for the night or two preceding each of the present experiments.

TABLE 11. *The influence of alternative supplies of wheat upon the percentage of wheat taken from the original source*

Expt. No.	1					2					3			
	Normal		*Alt. supplies*			*Normal*		*Alt. supplies*			*Normal*			*Alt. supplies*
Date (1942):	*Av.**	*/2*	*/3*	*/4*	*/5 Feb.*	*Av.**	*/7*	*/8*	*/9*	*/20 Aug.*	*Av.**	*/22*	*/23*	*/24 Aug.*
6–9 p.m.	26	26	21	11	13	6	10	6	4	6	11	14	19	14
9–12 p.m.	21	18	14	11	17	23	23	21	17	18	33	27	20	17
12–3 a.m.	21	16	17	13	13	32	25	9	8	7	28	27	30	16
3–6 a.m.	27	19	12	13	17	35	35	20	14	10	26	31	29	22
6–9 a.m.	6	14	9	13	7	4	7	3	2	3	2	1	2	3
Alt. supplies		7†	27	39	33			41	55	56				29
Total take (g.).	1,734	2,150	2,137	2,048	2,188	2,622	2,865	2,945	3,498	3,458	2,622	3,458	3,619	4,037

* Averages are for (1) 12–20 Dec. 1941 and 2–7 Jan. 1942 combined; (2) 10–20 July 1942; (3) 10–20 July 1942 corrected to British Summer Time (G.M.T. + 1 hr.).

† In Feb. 1942 a small alternative source of wheat was available besides the main ones.

In experiment No. 1 three 800-g. piles of wheat were placed around the hopper (squares NS, VW, and U, Ch. 4, Fig. 2). (There was also some wheat available elsewhere before and during this experiment; but as little was taken the main argument is not affected.) On 2/3 February, the first night that the extra 2,400 g. was available, 73% of the total take was still from the hopper, and on the two succeeding nights 61% and 67%. Table 11 gives 3-hourly records from the apparatus showing that practically no attention was paid to the new wheat piles during the first 3 hours of feeding on the night that they were placed. (The full records show that takes from the hopper during the first 1½ hours of feeding were identical on this and the preceding night, before the piles were placed.) Apparently the piles did not operate as new objects to the extent of depressing the feeding at the normal site, although this behaviour has sometimes been observed. Whereas the previous average consumption after 3 hours had been 25·5% of the total night's take from the hopper (Chitty and Shorten, 1946), on

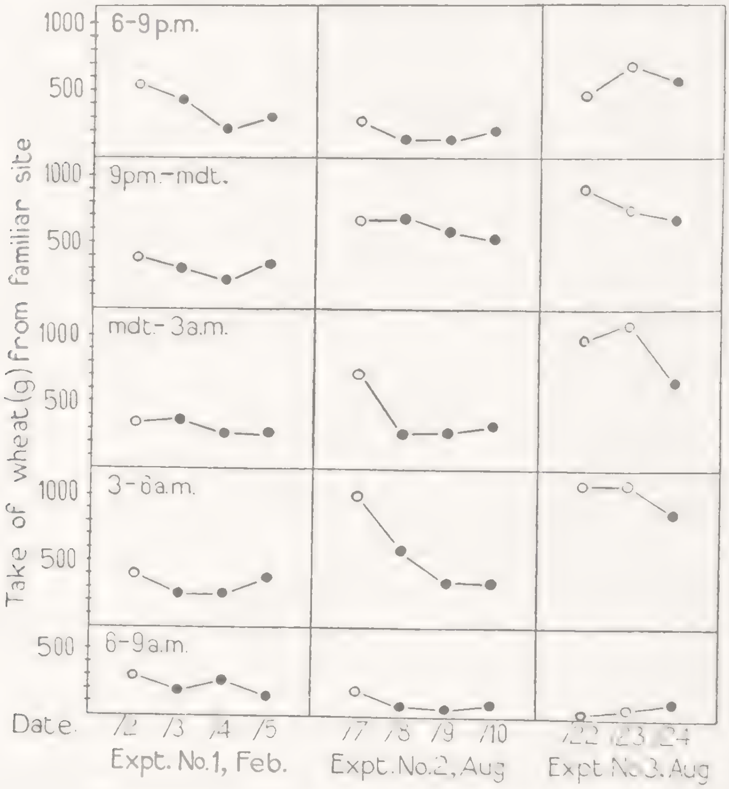

FIG. 1. The amount of wheat (g.) taken from a familiar site before and after the provision of alternative supplies of wheat: 3-hourly takes (g.) on successive days, calculated from data in Table 11. Black dots show days on which alternative supplies were available.

the first night of placing the wheat piles 21% of the total was still taken in that time from the usual source. On the two succeeding nights the rats apparently became more adapted to the new food sites, and only 11 and 14% of the total night's take was recorded from the hopper in the first 3 hours. The results for all 3 days, however, illustrate a remarkably strong attachment to the accustomed feeding site and a great reluctance to change to an easily available alternative. This avoidance may not have been because of new object reaction, but probably illustrates the highly conditioned behaviour of the brown rat which is responsible for its slow adaptation to changes in the environment.

In the second experiment, two 1-kg. piles of wheat were placed on the floor of the shed, one under the window and the other at the side and slightly in front of, the hopper (squares PQ). The first pile was not much used, as only 190 g., 65 g., and 100 g. wheat were taken from it in 3 days. The other pile was all taken on the first night; on the second night 2 kg. were taken, and on the third night 1,850 g. out of 2 kg. However, comparison between the half-hourly takes from the original food source (the hopper) on these days and those before, showed that a negligible amount was taken from the piles before midnight. Compared with the normal feeding curve there was a reduction from 31·4 to 27·7 in the percentage of the total night's take eaten in that period. Between midnight and 3 a.m. and in the succeeding interval the take from the hopper was greatly reduced. On the second and third nights the rats mainly followed their accustomed behaviour of going to the hopper first and to the new piles only after the initial burst of feeding was over.

A further illustration of this phenomenon is given by an experiment in which food was removed from the accustomed site and placed nearby. The rats took some time to abandon an intermittent type of feeding and at first used to go to the original site and thence to the new one, thereby travelling two sides of a triangle. This route was gradually abandoned for the direct one, but on the following evening one individual was still travelling via the original site.

The third example in Table 11 was as follows. Four multiple-catch wire-traps had been in place with the back doors open since 4 July, when they had last been used for trapping this population. (Their positions were: (1) immediately east of the hopper, (2) 4½ ft. south of square P, (3) under the light, (4) at the corner of the observer's screen. On 23/24 August each was well supplied with wheat outside and inside both compartments by way of prebaiting before being set on 25/ August. A comparison of the amounts of wheat eaten in each 3-hour period showed once again the strength of the prebaited behaviour, for although in this case there was slightly more effect before midnight, the significant diversion to the new supplies came only in the period 12 to 3 a.m. The consumption by midnight (B.S.T.) had previously been 40 and 39% of the total night's take (slightly less than the 44·2%, that had been eaten by the same time in July, 1 a.m. D.B.S.T.). When the traps were prebaited, 32% of the total take was eaten from the hopper by midnight; but from 12 to 3 a.m. only a further 16% was eaten compared with a further 28 and 30% on the two previous days. (After 2 days of token baiting the traps were set and caught seventy-eight rats, reducing the subsequent food consumption to about half. Thus the population during late August had probably been about 160 rats.)

In experiments Nos. 2 and 3 there was some increase in total take when alternative food was available and takes as per cent. total cannot be interpreted too strictly. In Fig. 1 takes are plotted in grammes and again the new sources of wheat are shown to have been least successful in attracting the population early in the night.

(*l*) **Summary and discussion**

A brief summary of the previous section may enable us to assess the different reasons why 'new object reaction' occurs and to see which have the strongest and most lasting effect on the rat. In order of importance, these were found to be:

1. *Reaction towards a new object placed in the environment* may be very strong, and last for a period of 4 weeks or more in extreme cases. (If the object is remote from the food source a less striking reaction may be expected if measured by food take.)

2. *The placing of a new container for the food* affects the food supply so closely that it must be expected to be reflected very strongly in the feeding behaviour. This has been demonstrated.

3. *A change in the food* offered to the rat may cause a lowering of the food take for 2 days. (If the palatability of the food is very different the reaction may be expected to be prolonged or shortened.)

4. *A general disturbance of the habitat* induces a reaction similar to that caused by placing a new object. Unfortunately we have no data on the duration of this effect.

5. *Moving a familiar object* causes a weaker and shorter reaction than does the introduction of a new object.

6. *Changing the position of the accustomed food* results in a reaction during the initial burst of feeding, but the effect is apparently overcome during the night.

7. *Noise* may operate as a disturbance for a short time with normal rats; if the rats are disturbed by some other factor, the effect of noise is greater.

8. *A change in strength of the illumination* of the habitat was not found to be an important disturbing factor. A few cases of rats interrupting feeding for this reason are recorded, but graphs of normal feeding, when compared with feeding under different strengths of artificial lighting, give the impression that this factor is not so important for the rat.

9. *Hunger.* It might be expected that great hunger would exert a pressure to overcome any reaction that disturbed feeding, but there are insufficient data on this subject. An experiment is quoted in this paper in which rats that had been on a token bait for 20 days were observed to show a strong new object reaction when their food was placed in a metal tray. For the succeeding $3\frac{3}{4}$ hours feeding stopped completely.

10. *Distance and material of disturbing factors.* There is some evidence, both in the literature and in our work, that the strength of a reaction towards a new object such as a trap may vary with the materials used and the height of the roof.

11. *Odours.* Experiments quoted at the beginning of this paper indicate that the cause of new object reaction is not human odour left on the objects by handling. There is little reaction to the smell of zinc phosphide.

12. *The removal of the factor causing new object reaction* does not in itself constitute a disturbance. Rats that had overcome their fear of new containers sufficiently to feed from them showed no disturbance in feeding behaviour when the containers were removed.

4. 'NEW OBJECT REACTION' IN CONTROL WORK

(*a*) Summary of principles

It has been shown in the foregoing sections of this paper that the sensitivity of the brown rat towards new situations in its environment must be taken into account when rodent control work is being carried out. Experiments under more or less artificial conditions, backed by many examples from other field operations, have yielded evidence of the extent to which the rat may be disturbed by various types of change in its surroundings.

When rodent control is being carried out, a very important part of the work is to condition the rats to feed, while they are still hungry, on particular baits at chosen sites. A pattern of behaviour is thus induced which is maintained until the introduction of poison into the bait has brought about the death of all successfully conditioned rats. Factors which disturb this habituation lower the efficiency of the control measures.

Prebaiting introduces the rats to the bait before the crucial time of poisoning, and also forms in them a habit of taking food from the chosen bait points. Suspicion towards a new food may prevent the rat from eating a poison bait laid without prebaiting, until later in the feeding period, when the rat is not so hungry. Either complete refusal or sampling may occur, causing a low kill. The baits may not be discovered until after other food has been taken, if they are laid in places where the rats are not accustomed to feed. The importance of laying the baits in the same places during successive prebaiting nights is apparent, if the rats are to be conditioned successfully.

When containers are placed in the environment they constitute new objects; for this reason they are avoided or treated with extreme suspicion by the rats for some time, even if they are baited with food in habitats where food is scarce. 'Lag' or the length of time taken by the first rats to overcome their suspicion and enter the container varies somewhat under different conditions; but 10–14 days is the usual maximum in most situations. After the period of lag there is usually a gradual daily increase in the amount of food taken from the container, this being termed the 'build-up' period. Various factors affect the rate of the build-up; discovery and imitation among the rats probably play a part. Even where the bait is not placed in a container, a short build-up to a steady take may be observed; this being due, probably, to the discovery factor, which may be coupled with a preliminary suspicion of the new food.

During the time that the containers are being kept baited the operator must take care that his daily visit to the environment is made without causing any alteration to the habitat that might alarm the rats. Replacing the container in a different place, or at a different angle, the removing of cover-material, or other such actions may result in disturbance of feeding behaviour. Where such a disturbance is made on the night that the poison is placed the poisoning may fail because of the effect. Where poison is not laid in containers, but in runs and under existing cover, it may be necessary to take special precautions to prevent other animals getting poisoned. Disturbance of the habitat such as moving the cover or blocking access from some directions must be done in advance of the poisoning.

(*b*) Examples

(i) *'Lag' in entering the P3*. Apart from their use as containers for prebait and poison bait, P3s have also been used for census baiting. In this way evidence has been collected about the time taken for the population to become used to feeding in a P3 placed in their environment; with token baits this is not possible.

The aim of the census is to secure a series of figures representing the daily take of wheat of the population living within range of the containers. As new object reaction is expected towards the containers at first, they are baited with a handful of wheat and left undisturbed for a period of 10–14 days. At the end of that time they have usually been entered by the rats and all the bait has been taken. A surplus of wheat is then placed in them, and daily measurements and replenishings take place. The amount eaten each day generally increases (the 'build up' period) until a steady level is reached.

A survey of twenty-two localities in which varying numbers of P3s were placed showed a lag of 0–12 days before there was evidence that rats had entered any of them. This range of time is fairly representative of all but a few very 'difficult' populations. A similar variation in lag has been found between different P3s within a single infestation.

The period of lag may indicate only the time taken for the bolder members of a rat population to overcome their suspicion of the container; other rats may not enter until the 'build-up' period. The factors resulting in the build-up are not known with exactitude, but it seems likely that they include the discovery of the container and overcoming of new object reaction by the late arrivals, together with less and less suspicious feeding by the first arrivals. The build-up varies with different populations and is no doubt influenced by the number of containers used and the positions chosen. Even where, 14 days after placing, there followed a period of token baiting, the build-up on surplus wheat was still noted, although it tended to be of shorter duration.

(ii) *'Lag' in entering pipes.* What has been said about suspicion and the discovery factor affecting the entry of P3s in the field also applies to the other standard container, the pipe. For example, when a small population of rats living on a pig farm was offered wheat in pipes, there was a lag of 6 days before entry was recorded. Token baits of bread mash, on the other hand, were taken on the first night when they were placed in nearby holes. In another test when forty pipes were placed on a rubbish dump the first entry was recorded on the second day, but it was not until the thirteenth day that all had been entered.

The build-up of the total night's take is much the same with pipes as with P3s and again may occur even after a period of token baiting. After all the wheat placed in the pipes during an initial period had been eaten by certain rats, 200 g. of wheat was placed daily in each group for the next 4 days, and all was eaten. After a gap of 1 day a surplus of wheat was placed. A build-up was observed, even after this long preliminary period: 820, 1,010, 1,310, 1,495, 1,690, 2,080--, 1,990 g. In a large population such as this, it may be imagined that a small bait such as 200 g. per baiting point would be eaten by the first arrivals and prevent the rest of the population from learning to feed from the pipes.

It has already been mentioned that the figures quoted for lag and build-up time are normal for all except 'difficult' populations. Venables recorded that difficulty was experienced in overcoming lag in entry to pipes primed with wheat in the late summer. This difficulty was experienced at some localities for three consecutive years. At other seasons it was easier to draw the rats into the pipes, the maximum period of lag being 2 weeks. In a semi-rural poultry yard, baited pipes were placed on 12 July; but there had been no feeding from them by 2 August. A similar poultry yard was treated in the same way in April; and here the rats entered the pipes after the normal lag period. Because of this refusal to enter pipes at this time of the year a few experiments were abandoned. Pipes laid for census records on another farm were entered reluctantly, and a peak take of 540 g. was recorded. Yet at poisoning forty-one bodies were picked up; the rats were not fully conditioned to feed in the pipes although there were ten of these laid. There was no postbait take, although it was known that 3-4 rats were there. The presence of abundant cereals stored in one of the buildings, and a field of almost ripe corn nearby, may be supposed to have lessened the possibility of conditioning the rats to feed from the pipes.

(*c*) Failures in poisoning

There are few examples of new object reaction actually causing a failure in poison baiting in the field; once it was realized how dangerous this factor could be to the success of control work care was taken to guard against it.

There is one record from our early work of the reaction occurring on the night of poisoning and causing a failure: a small population of rats (peak take 355 g. wheat) living in a disused room in a market was prebaited to feed on wheat from the food-recording machine. A change of pipes was made on the night of poisoning, and as a result of the disturbance (cf. Table 7) feeding was 1 hour late in starting. Also the take of poison bait was less than 4% of the peak take of wheat (it is usually 8–11% although lower takes do occur—Ch. 7).

In one other example a poisoning failure was due to new object reaction. Here the failure was intentional, as it was necessary to secure survivors from a sub-lethal dose of the poison. For the 2 nights of the first poisoning a shallow tin tray was introduced into the environment to hold the poison bait, as a result of which almost none was taken. This was followed by a second poisoning without the disturbing factor and considerably more poison bait was taken. The fact that the majority of the rats appear to have been killed the second time suggests that they did not take enough poison bait in the presence of the new object to become shy of a further dose.

(*d*) ***Rattus norvegicus*** **and** ***R. rattus***

The behaviour described in this paper applies to the brown rat (*R. norvegicus*) and it is uncertain whether or not similar behaviour is exhibited by the ship rat (*R. rattus*). The data we have on new object reaction in *R. rattus* is insufficient (Ch. 13); but an interesting comparison is made in Ch. 14, § 2 (*c*) which suggests that black rats are less shy of entering containers.

5. SUMMARY

1. Brown rats have a natural form of behaviour, referred to here as 'new object reaction', which is exhibited when their environment is disturbed.

2. This suspicion is not caused by human odour due to the handling by man of objects in the environment. The principle of using substances with odours strange to the rats as repellents is discussed; in many cases the effect observed may be due to new object reaction rather than a dislike of the odour *per se* or of associations it evokes. Duration of the reaction to the 'repellent' might give a clue to this.

3. Some suggestions were found in the early literature on the senses and psychology of the white rat as to which senses reveal the presence of a new object to the rat. This aspect, and the question of why the rat reacts to a new object as it does, is not covered by our work. It is suggested that sight may be of less importance than the olfactory sense and the vibrissae. Extreme caution is necessary in arguing from the white to the brown rat.

4. Five different methods of studying new object reaction are described: (*a*) direct observation, (*b*) analysis of data from continuous automatic

records of the rats' feeding activity, (*c*) comparison of total daily takes of food, (*d*) examination of tracks, (*e*) study of reactions towards poison baits.

5. The factors observed to cause new object reaction were (*a*) the placing of new objects near a food supply, (*b*) the use of a newly introduced container for the food, (*c*) the moving of a familiar object, (*d*) a new type of food, (*e*) changes in illumination, (*f*) noise, (*g*) general alteration of the habitat.

6. The removal of a disturbing factor from the environment does not, in itself, bring about a further reaction.

7. Observations suggest that the material of which a new object is made, and its distance from the path of the rat, influence the strength of the reaction shown towards it.

8. Three instances are quoted where an easily available supply of food was provided for rats accustomed to feed at one place. Their pattern of behaviour changed only gradually.

9. There is some variation in the strength of the reaction towards the different types of disturbance. The effect of hunger on new object reaction has not been studied.

10. If not allowed for, new object reaction may greatly lower the efficiency of control measures. Rats show reluctance to enter bait containers and failures in poison baiting have been caused by new object reaction.

11. Insufficient data on new object reaction in *R. rattus* prevents a comparison of the ship rat with the brown rat.

REFERENCES

Anon. (1777). 'The complete vermin killer; a valuable and useful companion for families, in town and country. . . .' 4th ed. 87 pp. London.

Boulenger, E. G. (1920). 'Report on methods of rat destruction.' Proc. Zool. Soc. Lond. 1919: 227–44.

Brians, F. (1938). 'Discussion on rodents—rat and mice control.' Exterminators' Log, Kansas City, Mo. 6, No. 3: 15–19.

Carr, H. A. (1917). 'Maze studies with the white rat. 1. Normal animals.' J. Anim. Behav. 7: 259–75.

Carr, H. A., & Watson, J. B. (1908). 'Orientation in the white rat.' J. Comp. Neurol. 18: 27–44.

Chitty, D., & Shorten, M. (1946). 'Techniques for the study of the Norway rat (*Rattus norvegicus*).' J. Mammal. 27: 63–78.

Dennis, W. (1929). 'The sensory control of the white rat in the maze habit.' J. Genet. Psychol. 36: 59–89.

Doty, R. E. (1938). 'The prebaited feeding-station method of rat control.' Hawaii Plant. Rec. 42: 39–76.

Ford, L. A., & Clausen, D. F. (1941). 'Rodent repellent tests: *n*-butyl mercaptan against white and wild rats.' Industr. Engng Chem., News Ed. 19: 783.

Richter, C. P., & Emlen, J. T. (1945). 'A modified rabbit box trap for use in catching live wild rats for laboratory and field studies.' Publ. Hlth Rep., Wash. 60: 1303–8.

SMITH, R. (1768). 'The universal directory for taking alive and destroying rats, and all other kinds of four-footed and winged vermin, in a method hitherto unattempted, calculated for the use of the gentleman, the farmer, and the warrener.' By Robert Smith, rat-catcher to the Princess Amelia. 218 + vii pp. London.

SOUTHERN, H. N., WATSON, J. S., & CHITTY, D. (1946). 'Watching nocturnal animals by infra-red radiation.' J. Anim. Ecol. 15: 198–202.

VINCENT, S. B. (1913). 'The tactile hair of the white rat.' J. Comp. Neurol. 23: 1–38.

6

THE AMOUNT OF WHEAT CONSUMED BY THE BROWN RAT

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With an Appendix by R. B. FREEMAN

1. INTRODUCTION

THE method of prebaiting a population of rats with a surplus of wheat yields information about the degree of rat infestation. Evidently, if the wheat take can be translated into number of rats, the surplus prebait technique provides a rough census of the population, and the application of this method was discussed by Chitty (1942). In the early stages of the Bureau's work the approximate figure of 30 g. wheat per day per rat had been used for this purpose, and it was in order to check this figure that the experiments discussed in this paper were in the first place designed.

Apart from this practical application of the results, it also seemed desirable that some accurate measure of the rat's food consumption should be made under properly controlled experimental conditions. Several estimates are to be found in the popular literature and are handed down from author to author without much critical appreciation of the basis, if any, on which they were first determined. Many of these estimates are complicated by what appears to be some entirely arbitrary assumption as to the amount of food damaged or wasted over and above the actual amount eaten. Throughout the following observations, and any calculations based on them, no attempt has been made to measure the amount of waste or damage. All the figures are to the best of our knowledge the actual amount of wheat which was eaten. Damage and waste are necessarily very variable; but in some circumstances the amount is probably considerable. Any allowance for these factors would only add materially to the results presented in this paper.

2. METHODS AND RESULTS

The wild *R. norvegicus* which were used in these experiments were taken from four different types of habitat: a pig farm, a slaughter-house, sewers, and corn-ricks; and they were caught either in various kinds of live traps or by hand at threshing. On their arrival at the laboratory each individual was sexed and weighed to the nearest 5 g. in a container on a spring balance. It is difficult, however, to record the body weight of live wild rats with any high degree of accuracy, owing to their continuous and jerky movements. The weights are therefore subject to a small additional error resulting from the movements of the pointer on the balance. No female which was obviously pregnant at the time of capture was admitted to the experiments. A grand total of 120 rats (60 ♂, 60 ♀) was observed and only those animals which were apparently in good health during the time the food measurements were being made are included in the results. The data can be divided into three main groups: (1) Twenty-two rats (9 male, 13 female) observed in single cages in the laboratory and fed on whole wheat. (2) Nine rats (4 male, 5 female) also observed in single cages in the laboratory, but fed on kibbled wheat. (3) Eighty-nine rats (47 male, 42 female) divided into seventeen groups of individuals and observed in outdoor cages (Ch. 4, p. 169).

The methods of housing the animals and of recording the observations were as follows. Individuals observed under constant conditions in the laboratory were each kept in separate cages (2 × 3 × 1 ft. high) and the food —either whole or kibbled wheat—was given to them in large food tins ($5\frac{1}{4} \times 4\frac{1}{2}$ in.) to reduce waste by spilling to the minimum. The amount of spilling which actually did occur was not such as to alter materially the results set out below. The temperature of the animal house in which they were housed was kept at around 70° F., the maximum and minimum range generally being about 65–75° F.

The amount of food consumed in 24 hours was recorded each day, and the mean consumption of food per day was then estimated for the period of observation in the case of each animal, neglecting the first day's results whenever the records began immediately on arrival in the laboratory. The body weights were not recorded each day, since it was considered that the disturbance caused to these wild rats by a daily series of weighings was best avoided. In the case of eleven rats (5 male, 6 female) the body weight was recorded a second time after an interval varying between 18 and 43 days. Judging from the results it would appear that on the average the males remained fairly constant in weight, while the females over 200 g. tended to lose weight. The amount of loss was not very great and amounted on the average to 1·1 g. per day. Since no signs of obvious pregnancy developed in any of the females housed in the laboratory, and no remains of any embryos were found in the cages, it seems fairly certain that they were neither pregnant nor lactating over the period of observation. The average daily consumption of food of the thirty-one individuals observed in the laboratory is given in Table 1, where the initial body weight and the period of observation are also recorded in each case.

The remainder of these experiments were carried out in outdoor colony cages, one of which had a floor space of 36 sq. ft., the four others 50 sq. ft. The rats lived in burrows in a large heap of earth on a concrete base. Food was given either in P3s or in a large box containing one or more food tins. An adequate water supply was constantly available. As originally planned, each experiment in this series was to be made on a group of individuals of the same sex and whose range of body weight did not exceed 100 g. In practice, however, it was found that these conditions had to be relaxed somewhat, since a sufficient number of the same sex, all lying within a weight range of 100 g., could not be obtained at will from such wild populations as were available locally for trapping. In eight groups of animals the sexes were mixed, and out of a total of seventeen groups the difference between the lightest and heaviest animal was less than 100 g. in nine groups; between 100 and 150 g. in seven groups; and above 150 g. in only one group.

TABLE 1. *Rats fed on whole wheat in the laboratory*

Males			*Females*		
Body weight (g.)	*No. of days observed*	*Mean consumption per day (g.)*	*Body weight (g.)*	*No. of days observed*	*Mean consumption per day (g.)*
85	10	13·0	80	18	13·2
115	10	11·2	80	10	12·7
125	9	11·1	110	9	11·9
190	13	21·0	120	21	8·3
230	13	23·5	120	13	15·1
275	9	20·1	125	27	12·8
395	8	27·7	155	10	13·4
400	13	25·9	190	13	20·7
410	8	25·1	230	13	20·0
			290	13	22·2
			330	13	22·7
			370	13	29·3
			[480	8	14·8]*

Rats fed on kibbled wheat in the laboratory

Males			*Females*		
Body weight (g.)	*No. of days observed*	*Mean consumption per day (g.)*	*Body weight (g.)*	*No. of days observed*	*Mean consumption per day (g.)*
70	5	8·9	85	5	12·5
75	5	9·0	165	5	13·9
250	5	16·3	165	5	16·3
287	5	19·9	180	5	11·7
			180	5	12·2

* Neglected in the analysis, see text (rat No. 58).

The results of this series of experiments are given in Table 2, together with the mean maximum and minimum shade temperatures recorded in the cages during the course of each experiment. In calculating the mean daily consumption of wheat per rat, the first day's food take was neglected and in one instance the first 3 days. This initial figure was almost invariably much below the take on the second and subsequent days, this being, presumably, a reflection of the shock of capture and of the changed conditions of living. Apart from this first day, however, the rats appeared to settle down very quickly in their new environment, if the consistency of their daily food intake can be taken as an indication of a successful readjustment to their changed conditions.

TABLE 2. *Rats living in outside cages and fed on whole wheat*

No. and sex of rats ♂	♀	*Mean body weight* (*g.*)	*Range of weights* (*g.*)	*No. of days observed*	*Mean consumption* (*g.*) *per day per rat*	*Mean max. shade temp.* (° *F.*)	*Mean min. shade temp.* (° *F.*)
..	3	50	45–56	1	7·7	65·0	53·0
8	7	65	30–125	2	14·5	51·0	41·5
3	..	83	70–100	11	15·3	70·4	54·3
5	..	95	85–110	11	13·0	69·3	46·2
4	..	110	100–120	7	15·4	87·8	52·2
..	6	196	165–215	11	19·8	81·5	59·0
1	5	220	155–300	4	30·2	50·3	43·7
2	1	227	165–310	7	28·8	54·2	35·6
3	3	255	150–330	4	32·1	50·3	43·0
..	3	273	230–300	10	30·5	59·6	46·7
4	2	299	245–375	3	35·0	46·3	43·0
1	4	326	275–380	9	29·1	49·6	42·0
4	5	342	285–390	4	27·2	54·7	32·0
4	..	345	290–395	9	36·9	42·6	27·8
6	..	351	285–415	3	36·5	46·5	37·0
..	2	422	420–425	10	31·7	71·3	47·0
2	1	509	492–535	11	39·2	52·9	38·7

In four of these cage experiments the rats were re-trapped alive at the end of the period of observation and their weights recorded. Four other groups were finally used in poison experiments and thus the weights of the dead animals were available for comparison. In poison experiments, however, the animals do not necessarily die all on the same day, and some individuals, owing to illness, may have a low food intake for a number of days before death. Thus the weight of animals dying from poison tends to be below that of the live animal at the beginning of the experiment. It was concluded from these comparative figures that the mean body weight of the groups of animals changed very little and could be assumed to remain constant over the periods of observation. Although no female obviously pregnant was admitted to these cages, it is possible that both pregnancy and lactation may have occurred during the period of observation. This was difficult to determine under the conditions of the experiments, since the buries made by rats in the earth provided were not disturbed in any way during the time of observation. Since the measurements of food take were begun 24–48 hours after arrival, and since the maximum period of observation was 11 days (average 6·9 days), it seems most unlikely that many females would have given birth to litters during this time.

3. ANALYSIS OF RESULTS

From a preliminary survey of the results given in Tables 1 and 2 it appeared that if y be the consumption of food per day and w the body weight, then, approximately:

$$\log y = \log a + b \log w$$
$$\text{or} \quad y = aw^b$$

Assuming this linear relationship between the logarithm of the consumption of food per day and the logarithm of the body weight, the values of the constant b were determined for each of the three main groups of data.

(*a*) Whole and kibbled wheat in single cages

Among the rats fed on whole wheat in the laboratory the mean daily consumption of one individual (rat No. 58) was so widely divergent from the other figures, that it was neglected in the analysis. This female was apparently in good health and we have no explanation for her abnormally low intake of food considering her size. The principal points which emerged from the analysis of the data for the remaining thirty individuals in Table 1 may be summarized briefly as follows:

Sex differences. Comparing the nine male and twelve female rats fed on whole wheat, no significant differences either in the position or the slope of the regression lines for the separate sexes could be established. Thus it appeared that weight for weight the females ate on the average the same quantity of wheat per day as the males. In consequence the data for males and females were pooled.

Regression coefficients. The values of the regression coefficient b were estimated to be:

Rats fed on	*b ± standard error*
Whole wheat	0·57020 ± 0·07004
Kibbled wheat	0·44615 ± 0·10262

The difference between these values of b is insignificant. Some evidence was obtained that the rats may have been consuming slightly more whole than kibbled wheat, since in testing for any positional difference between the two regression lines the value of t was 2·20, which for 26 degrees of freedom is just significant, P lying between 0·05 and 0·02. The difference, however, is not very great and it is uncertain how much of it might be accounted for in terms of some slight degree of waste.

(*b*) Whole wheat in outdoor cages

The experiments above were all carried out under fairly constant conditions of temperature in the laboratory and the individuals were living in separate cages. The remainder of the experiments (Table 2) were made with groups of animals living under more natural conditions, in so much as the individuals were able to make their own buries in the earth and had a larger area over which to roam; but they were also subject to a variety of environmental conditions, the experiments having been carried out at different times of the year. Apart from the effect of body weight, it seemed likely that the consumption of food might have been affected by the temperature of the environment in which they were living, and also, possibly, by the number of rats in any particular population or group. The only temperature records which were made were the mean maximum and minimum shade temperature in the cages over the period of each experiment. While it is true that these figures are in some degree a measure of temperature conditions under which these rats were living, since they came into the open in order to feed and to move about the cages, yet a large part of their time was spent in the earth buries, to the temperature of which the mean maximum and minimum shade temperature in the open can only have borne an indirect relationship. However, there seemed to be no simple or obvious method of recording the temperature of the earth buries, or perhaps more precisely, of the nests in which the rats spent a large part of their time, particularly in daylight.

In addition, therefore, to the linear regression of log mean daily consumption per head on log mean body weight, partial regression coefficients were also calculated for mean maximum shade temperature, mean minimum shade temperature, and for the number of rats in the experiment. The estimated values of the four coefficients, together with their standard errors, were as follows:

Partial regression of log mean daily consumption per head on	*Value of regression coefficient*	*t* (*12 d.f.*)	*P*
Log mean body weight .	0·59669 ± 0·06660	8·96	< 0·001
Mean maximum shade temperature . . .	−0·0036946 ± 0·0019298	1·91	< 0·10 > 0·05
Mean minimum shade temperature . . .	0·0019116 ± 0·0033226	0·575	< 0·60 > 0·50
Number of rats in the group	0·0026927 ± 0·0058026	0·465	< 0·70 > 0·60

From the values of *t* given in the above table it is clear that, apart from the partial regression on log mean body weight, the only partial coefficient which approaches significance is that for the mean maximum shade temperature. If the last two coefficients, namely, those for minimum shade temperature and the number of rats, be eliminated from the analysis, the partial regression coefficients of log mean daily consumption per head on log mean body weight and on mean maximum shade temperature are 0·57253 ± 0·05268 and −0·0031808 ± 0·0012227 respectively. The coefficient for maximum temperature is now 2·60 times its standard error, and for 14 degrees of freedom P is very nearly 0·02. This evidence, which is not entirely conclusive, suggests that the consumption of food may have been affected by the maximum shade temperature or by some factor, or group of factors, closely associated with it. The negative sign of the coefficient indicates that the higher the maximum temperature the lower is the consumption of food, and vice versa.

(*c*) Comparison between the three groups

Neglecting this somewhat indefinite partial regression on maximum temperature, the value of b for the outside rats fed on whole wheat is $0{\cdot}63044 \pm 0{\cdot}05620$. In testing the three regression lines for differences in position and slope, we have for the analysis of variance:

	Sum of squares	*d.f.*	*Mean square*	*Variance ratio*	*P*
Single regression line .	1·26507	1	..	..	..
Differences in position .	0·21907	2	0·10953	21·41	< 0·001
Differences in slope . .	0·01105	2	0·005525	1·08	> 0·20
Pooled residual for three separate lines . .	0·20979	41	0·005117	..	..
Total . . .	1·70498	46	..	..	..

Thus, in comparing the three series of results it can be seen that, whereas there were no significant differences in the slopes of the regression lines, the positional differences were marked. Over the range of body weights studied, which was roughly between 50–500 g., rats living in the open were consuming more wheat per day than those living inside the laboratory. This difference in food intake might be explained, in part at least, by the differences in average temperature between the two environments. It seems likely that the heat loss among rats living in the open would be greater than among those living under the higher and more constant temperature conditions in the laboratory, more particularly in the winter. In addition, the size of the outdoor cages enabled the rats to live a relatively more active and natural life than that enjoyed by rats living in the much smaller cages in the laboratory. But, whatever the explanation of this difference may be, it is clear that the food consumption recorded in our outdoor cages is more likely to approach the consumption of the native wild rat, when food is plentiful.

Since it has been shown above that there was no significant difference between the slopes of the three regression lines, an estimate was made of the constant b in the equation $y = aw^b$, by finding the slope of the three best-fitting parallel lines which passed through the observed means of log y. This value of b was found to be $0{\cdot}58274 \pm 0{\cdot}04099$, there being

43 degrees of freedom for the estimation of the error. The values of a for the three curves were as follows:

Group of animals	*Value of a in the equation* $y = aw^{0\cdot58274}$
Outdoor rats fed on whole wheat	1·0804
Laboratory rats fed on whole wheat	0·82283
Laboratory rats fed on kibbled wheat	0·71460

Thus, on the average, rats living in the open consumed 1·313 times more whole wheat than those living in the laboratory.

The estimated consumption of whole wheat according to body weight is given in Table 3 for a few points on the first of the curves above. The range of weights considered covers most of the range which is likely to be met with in the majority of wild populations. A rat is almost certainly fully weaned by the time it is 50 g. in weight and observations by the Bureau on a large number of wild rats show that individuals above 550 g. are relatively rare. The range of error of the curve was arrived at in the following way. The mean of the seventeen values of $\log_{10} y$ observed in the case of the rats living in the open was 1·37807 and the mean of $\log_{10} w$ was 2·30715. Since the mean residual variance left after fitting three parallel lines to the data was 0·0051358 for 43 degrees of freedom, the standard error of the mean of the values of $\log y$ is $\pm 0\cdot01738$. Thus the full equation for the curve

TABLE 3. *Estimated consumption of whole wheat per day by rats living in the open*

Body weight (g.)	*Mean daily consumption (g.)*	*Range* ($P = 0\cdot99$)	*Mean daily consumption. % of body weight*
50	10·56	8·74–12·76	21·1
150	20·03	17·88–22·43	13·4
250	26·98	24·15–30·13	10·8
350	32·82	28·99–37·15	9·4
450	37·99	33·05–43·68	8·4
550	42·71	36·59–49·84	7·8

$$y = 1\cdot0804w^{0\cdot58274}$$

may be written, using logarithms to the base 10:

$$\log y = 0\cdot03360 + 0\cdot58274 \log w \pm t\sqrt{\{0\cdot0003021 + 0\cdot001680(\log w - 2\cdot30715)^2\}}$$

where the first quantity underneath the square root sign is the variance of the mean of $\log y$ and the second the variance of b. In Table 3 t was taken to be 2·7, which is the approximate value for 43 degrees of freedom corresponding to a level of $P = 0\cdot01$.

The mean daily consumption of food expressed as a percentage of the body weight is given in the last column of the table. It will be seen that a young rat of 50 g. eats daily just over 20% of its body weight, and that as the weight increases the percentage falls to about 10% for an animal between 250 and 350 g. and to about 8% at 500 g. These figures are, presumably, to some extent a reflection of a young rat's rapid growth in weight to begin with, which decreases markedly as the animal becomes older.

4. AVERAGE CONSUMPTION PER HEAD OF POPULATION

The relationship established above between the consumption of whole wheat per day and body weight in the case of the rats living in the open-air cages, was assumed to be the best estimate available of the food consumption of the wild rat living under natural conditions. These figures were therefore used to calculate the expected amount of wheat consumed per day by more or less complete populations of wild *R. norvegicus* which were examined by us in the laboratory and for which we had the distributions of body weight. In this way an estimate was made of the daily wheat consumption of the average member of a rat population. Although it is evident that this figure will vary somewhat according to the existing weight distribution of any particular population, it is necessary to have some factor of this kind if the surplus prebait technique is to be used as a rough census method of actual numbers.

When a population is prebaited with an excess of wheat, it is clear that the rats feeding at a particular prebait point are the active part of the population, and that nestlings and possibly some of those just leaving the nest are not represented, at least directly. Since, however, a lactating female is known to consume more food than a non-lactating or even a pregnant female (Cole and Hart, 1938), any unweaned young must in fact contribute indirectly to the total amount of food consumed. The possible effect of this complicating factor, which would tend to raise the consumption per head of feeding population, has been neglected in the following calculations, and we have worked throughout in terms only of weaned, or active rats, namely, those greater than 45 g. in weight.

In order to illustrate the variability which might be expected in the average daily consumption of wheat per head owing to differences in the weight composition of the population, two series of field data were used. The first of these was obtained from populations of rats which were inhabiting corn-ricks and which were killed at threshing. In this way a series of more or less complete cross-sections of rat populations in varying stages of development was observed. The records cover the period from 12 November 1939 to 29 April 1942, and a total of 4,369 active rats (2,026 male; 2,343 female) were examined. The threshing season extends roughly from the beginning of September to the end of the following July; but the ricks threshed early in the season are almost always free from rats. All active rats coming from ricks threshed between the above date limits were tabulated in seven body weight classes: in 50-g. intervals from 45 to 195 g.; and in 100-g. intervals from 195 g. and upwards, all rats above 495 g. forming a single class. The average consumption of whole wheat per head of active population per day was then estimated for the total population by applying the daily consumption of wheat calculated for the pivotal weights to the observed frequencies in each weight class and summing.

The observed weight distribution of these 4,369 rick rats is expressed per 10,000 in Table 4, and it will be seen that the estimated average consumption of whole wheat per head per day is 23·9 g. By applying the upper and lower limits of the range of error of the regression line according to the full equation given in the previous section, the range ($P = 0{\cdot}99$) of this average figure was estimated to be between 21·1–27·2 g. If these rick populations were taken as representative samples of the types of weight distribution which might be met with in all environments, then it would follow that in using prebaiting as a rough census method, it would only be necessary to divide the daily total take of whole wheat in grammes by the factor 24 in order to arrive at an estimate of the probable number of active rats feeding at some particular point. But to take, for example, a locality which has recently been invaded by a group of rats, the weight distribution of the population may be confined to the heavier body weight classes and there may be no active young present. In this case a higher factor such as 30 g. per rat per day would probably give a more accurate estimate of the population than the factor of 24 g.

TABLE 4. *Weight distribution and food requirements of wild rat populations*

Weight group (g.)	*4,369 rick rats (12 Nov. 1939–29 Apr. 1942)*	*379 non-rick rats (12 Nov. 1939–4 Feb. 1940)*
45–	2,339	633
95–	1,497	501
145–	1,138	528
195–	2,099	2,084
295–	1,760	2,507
395–	954	2,322
495+	213	1,425
Total	10,000	10,000
Mean body weight (g.)	220	338
Estimated average consumption of whole wheat per head per day (g.)	23·9	31·4

The degree of fertility which was observed in these rick populations was high throughout the threshing season, except for the months of June and July, when a considerable fall was usually recorded. The weight distribution at this season of the year, however, still reflects the high breeding rate during the previous months. If such a population were to breed at a low rate for some time, it is evident that a gradual approach will be made to a somewhat different type of weight distribution in which the older and heavier rats will tend to outnumber the young. We might expect to find this type of population in localities such as rubbish dumps, non-rick country environments, &c., during the winter months. The effect of such a change in weight distribution on the figure for the average amount of wheat consumed per day per head of population may be seen in the second example given in Table 4. The data on which the calculations were based were derived from a total of 379 active rats killed between 12 November 1939 and 4 February 1940. The majority of these rats came from a large and heavily infested rubbish dump, together with a few from non-rick country environments such as farm-buildings, hedges, &c. These non-rick rats were estimated to consume on the average a total of 31·4 g. of whole wheat per head per day, and the range of this estimate, obtained in the same way as in the preceding example, was from 27·5 to 35·8 g.

It is clear from these examples that it will be difficult to find any one factor for converting total consumption of wheat into numbers of rats, which would cover satisfactorily all possible cases. This census technique, however, has been suggested as a method of arriving at a reasonable estimate of the degree of infestation, rather than a precise method of enumerating the actual population. In applying the prebait-census method therefore, it is probably better to use the factor of 24 g. wheat per day in the case of a heavy or fairly heavy infestation, where it is more likely that the unknown weight distribution of the active population would approach the type observed in the corn-ricks; whereas in those cases where there is reason to believe either that the infestation is of recent date, or that fertility has been low for some time as in the non-rick winter populations, the use of a higher factor, such as 30 g. per day, would tend to give more satisfactory results in the long run. The use of any such factor, however, would only be valid in those cases where it can be justifiably assumed that the whole of the active population is feeding at some point or set of points.

5. COMPARISON WITH HUMAN FOOD REQUIREMENTS

From the general point of view the amount of whole wheat consumed by the rats observed in the laboratory can be taken as estimates of the calorie requirements, according to body weight, of individuals living under the conditions of the experiments. The measurements in the open-air cages would thus represent estimates, in terms of whole wheat, of the amount necessary to maintain life in the case of a moderately active rat, when food is plentiful. However, it will perhaps be of greater interest if these figures are converted into equivalent calories of flour and compared with the food requirements of man.

During the greater part of the war the National loaf in England was made from flour representing an 85% extraction of whole wheat and, according to McCance and Widdowson (1942, p. 108), 1 oz. National flour is equivalent to 101 cals. Taking 1 kilo of wheat equal to 1·874 lb. of National flour or 3,028 cals., then 1 g. of whole wheat is equivalent to 3 cals. The basic food requirements of an adult man at rest are usually taken to be 2,400 cals. per day, and those of an adult man doing a moderate amount of physical work, 3,000 cals. Either of these two figures might be taken as a convenient unit in which to express the rat's consumption: but the former figure, namely, 2,400 cals., has been chosen for the following reasons. The appropriate figure to use, from our present point of view, would be the calorie intake per day of the average member of the population of England and Wales, i.e. including infants and young adults. What the actual figure was during the war years we have no precise information, but it is reasonable to suppose, merely on common-sense grounds, that as regards order of magnitude it is likely to have been nearer 2,400 than 3,000 cals. per day. Thus, assuming that males between 15 and 60 years of age were engaged in a moderate amount of physical work (3,000 cals.) and using a series of sex and age factors such as those given by Bigwood (1939: last column of table on p. 96), we estimated that according to the age distribution of England and Wales in 1938 the food requirements of the average member of the population were approximately 2,520 cals. Taking into consideration the effect of war-time rationing, we tentatively assumed that the figure of 2,400 cals. usually given for the basic food requirements of an adult man at rest, was also roughly the same as the actual food intake for the average member of the civilian population as a whole. In the following type of calculation, the purpose of which is to compare orders of magnitude, such an assumption—rough though it may possibly be—is not likely to lead to any gross error.

Table 5 gives the average consumption of whole wheat per day of rats falling into a series of weight groups, assuming that the individuals in each group are concentrated at the pivotal weight. Taking 1 g. of whole wheat = 0·85 g. of flour = 3 cals., these figures for the average daily consumption are expressed both as a percentage of 2,400 cals. and as the number of rats in each weight group which would consume a total of 2,400 cals. in a day. It will be seen that a rat weighing between 45 and 95 g. with a pivotal weight of 70 g. will consume in terms of flour per day about 1·6% of a resting man's basic ration of 2,400 cals. This percentage figure rises with the weight of the rat as shown in the table, until at a pivotal weight of 545 g. it reaches the figure of 5·3%. The number of rats in each weight group which would consume a total of 2,400 cals. of flour in a day ranges from sixty-two in the lightest to nineteen in the heaviest weight group considered in these estimates.

The comparative figures for the average member of the two types of population considered in the previous section are given at the bottom of

Table 5. The body weight distributions from which these estimates were made differ quite considerably, the average active member of the rick populations weighing 220 g. and of the non-rick winter population 338 g. The number of rats in each type of weight distribution which would consume a total of 2,400 cals. of flour per day is thirty-three and twenty-five respectively. In round figures, therefore, it appears that thirty active rats living off whole wheat will in 1 day consume the equivalent of enough standard flour to satisfy the basic food requirements of an adult man at rest for the same period.

TABLE 5. *Comparative food requirements of rats and man*

Weight group (g.)	*Average consumption of whole wheat per day (g.)*	*Calories of flour as a % of 2,400*	*Number of rats which would consume a total of 2,400 cals. per day*
45–	12·8	1·6	62
95–	17·6	2·2	45
145–	21·5	2·7	37
195–	26·7	3·3	30
295–	32·6	4·1	25
395–	37·8	4·7	21
495–	42·5	5·3	19
Corn-rick populations .	23·9	3·0	33
Winter non-rick populations	31·4	3·9	25

It has been estimated in the case of the corn-rick populations that some thirty-three rats with an average weight of 220 g. would consume 2,400 cals. in a day, an amount roughly sufficient to provide a war-time day's rations for the average member of the civilian population when all age groups are considered. What the average body weight of the population of England and Wales is, we do not know at all precisely; but it may be roughly around 6–7 stone. Hence a biomass of 7¼ kilos of rat consumes the same amount of food as a biomass of some 38–44½ kilos of man. In terms of relative body surface, however, this discrepancy is not nearly so great. Assuming the conventional relationship of the body surface being proportional to (body weight)$^{\frac{2}{3}}$, thirty-three rats weighing 220 g. each would have a total surface of 1,203 units, while an individual of 6–7 stone would have a surface of 1,130–1,256. A similar calculation for the twenty-five non-rick rats, each weighing on the average 338 g. (biomass = 8·45 kilos) gave a total surface of 1,213. If, for contrast, we take the figure of an adult man weighing 65 kilos on the average and requiring 3,000 cals. per day when indulging in a moderate degree of physical work, the number of rats in the corn-rick populations consuming a total of 3,000 cals. will be found to be forty-two. These rats have a total surface of 1,530 units, while an individual of 65 kilos has one of 1,617. The equivalent figure for the non-rick type of population is thirty-two rats with a total surface of 1,553. Although these calculations are extremely rough—neither rats nor men are in reality perfect spheres—it is interesting to find that these comparative surface figures are of much the same order in both species.

6. SUMMARY

1. Experiments have been carried out on wild brown rats, observed both in single cages in the laboratory and in colonies living in open-air cages, in order to determine the amount of whole wheat eaten in 24 hours.

2. A definite relationship was found between the amount of wheat eaten per day and the body weight of the rat. Mathematically this relationship could be expressed by an equation of the type $y = aw^b$, where y is the amount consumed in 24 hours, w is the body weight and a, b are constants.

3. No significant difference could be established between males and females living in single cages and observed under constant temperature conditions in the laboratory. The general level of wheat consumption over the range of weights studied (roughly 50–500 g.) was significantly higher among rats living in the outdoor cages than among those living in the laboratory.

4. The conditions under which the individuals were living in these experimental open-air cages were the closest approximation we were able to obtain to those which must operate in nature. It was estimated that in 24 hours under these conditions a young rat of 50 g., for example, would consume on the average 10·6 g. of wheat; a medium-sized rat of 250 g. would consume 27·0 g., and a heavy adult of 550 g., 42·7 g. wheat. These representative values were obtained from the equation relating wheat consumption to body weight $y = 1{\cdot}08w^{0{\cdot}5827}$.

5. By applying this equation to the known weight distributions of wild rat populations which were examined in the laboratory, an estimate was made of the average consumption of wheat per head of population per day. Only 'active' rats, namely, those greater than 45 g., were considered in these calculations; and no allowance was made for the fact that a lactating female will eat more food than a non-lactating or even a pregnant female.

6. It was estimated that in highly fertile populations of rats inhabiting the corn-ricks, in which the balance of the distribution favours the lighter body weight classes, the average consumption of wheat per head per day was 23·9 g. In the case of another population type, in which the degree of fertility is low over some period of time, and which was represented in our samples by winter populations inhabiting such environments as rubbish dumps, country hedgerows, &c., the average per head per day was 31·4 g.

7. By converting the daily wheat consumption observed in these experiments into equivalent calories of flour, the results were expressed in terms of the basic food requirements of an adult man at rest, namely, 2,400 cals.

per day. In round figures it was calculated that on the average about thirty active rats will in 1 day consume an amount of whole wheat which, converted into flour of 85% extraction, would satisfy these requirements.

8. Certain figures are available in the literature of the amount of wheat eaten by rats (see Appendix). These are only conjectural, and are considerably higher than those observed in the present series of experiments. In most cases these figures cannot be directly compared because they include estimates of damage as well as consumption.

REFERENCES

BIGWOOD, E. J. (1939). 'Guiding principles for studies on the nutrition of populations.' Hlth Ser. L.O.N. Geneva. No. C.H. 1401. 281 pp.

CHITTY, D. (1942). 'A relative census method for brown rats (*Rattus norvegicus*).' Nature, Lond. 150: 59–60.

COLE, H. H., & HART, G. H. (1938). 'The effect of pregnancy and lactation on growth in the rat.' Amer. J. Physiol. 123: 589–97.

MCCANCE, R. A., & WIDDOWSON, E. M. (1942). 'The chemical composition of foods.' Spec. Rep. Ser. Med. Res. Coun. No. 235. 3rd impression revised. 150 pp.

APPENDIX

COMPARISON WITH PREVIOUS ESTIMATES IN THE LITERATURE

By R. B. FREEMAN

Certain figures for the amount of grain eaten by rats are available in the literature on rat control. These figures are, so far as we are aware, very largely conjectural and not based on accurate observations. They are estimates by 'recognized authorities' and cannot be directly compared with the facts put forward in this paper nor with the conclusions drawn. Most of them include estimates of grain damaged and are therefore much higher than those given here. These figures have been used as a basis for calculations on the total amount of damage done in Great Britain, an assumption being made as to the total number of rats. This question has been intentionally avoided here because such figures are entirely conjectural. These figures are also used to find the cost of the wheat consumed. On account of the fluctuations and artificial price of wheat and flour it is considered that comparable calculations from the figures in the present paper would be deceptive.

The earliest statement is in an agricultural calendar of 1800 (Anon.) where the author, before going on to calculate the costs of rat damage, supposes that 'a rat will consume half a peck of wheat in a week'. This figure corresponds to about 500 g. per rat per day.

The majority of recent statements of wheat consumption are, however, based on those of Rodwell (1850, 1858) and Lantz (1921). The original statements in Rodwell's second book are typical of the methods by which figures are arrived at and justify quotation at some length. On p. 168 he says: 'At a late meeting of Farmers ... it was generally agreed, in reply to the author's questions, that with eating and wasting, they [rats] would destroy half a pint of grain every twenty-four hours; and that six rats would eat, day by day as much as an ordinary man.' It should be noticed that no experimental work was done at all. On p. 169: 'Suppose there are 512 wine-glasses or half-gills, at strike measure, in a bushel; if 500 rats eat only a wine-glass, or half-gill of corn each, every 24 hours, and you allow 12 glasses only for waste, then they dispose of a bushel of corn per day.' Again the figure is only supposition. On the amount damaged he states, p. 169: 'I have at times seen them bite through and let fall four, six, and even eight grains out of ten.' Also that, in the best sample he could buy, 420 grains out of the 1,220 contained in half a gill were small, shrivelled, and unsound and that this one third would all be wasted by the rats. Rodwell's statements have been enlarged upon by Hovell (1924) who calculates the consumption by different numbers of rats of wheat, flour, and the equivalent number of quartern loaves.

The first statement of consumption and damage quoted above from Rodwell, gives a figure of 215 g. per rat: that in the second gives a figure of 55 g. for consumption alone. Taking his maximum figure for damage—eight out of ten grains, the actual consumption out of the half pint per day will be 43 g. per rat. For a full grown rat of 550 g. the comparative figure in this paper is also 43 g. For an adult rat of 250 g., however, the comparable figure is 27 g. and the average for the whole active corn-rick populations 24 g. Hovell states clearly that the figure is for a full-grown rat, but no such statement is in Rodwell's original.

Lantz (1921) states that the average quantity of grain consumed by an adult or half grown rat is fully 2 oz. daily or 45–50 lb. per year. It is not known whether this figure is based on Rodwell's 1 half-gill; 1 half-gill does weigh about 2 oz. This figure is probably the basis for the statement given by the M.O.F. in 1942 that 'one rat will eat nearly one half hundredweight of grain or its equivalent in a year'. The figure of 2 oz. (56·75 g.) per adult or half grown rat is 110% higher than the comparable figure of 27 g. given in this paper for a rat weighing 250 g.

REFERENCES

Anon. (1800). 'The new farmer's calendar; or monthly remembrancer, for all kinds of country business.' 616 pp. London.

Hovell, M. (1924). 'Rats and how to destroy them.' 465 pp. London.

Lantz, D. E. (1921). 'House rats and mice.' Fmrs' Bull. U.S. Dep. Agric. No. 896, 24 pp.

[Ministry of Food] [1942] 'Rout out the rats.' [4 pp.] London.

[Rodwell, J.] 'Uncle James' (n.d. [1850]). 'The rat! and its cruel cost to the nation.' 47 pp. London.

Rodwell, J. (1858). 'The rat: its history and destructive character.' A new ed. 299 pp. London. [1st ed. is before 1850.]

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THE CONSUMPTION OF PLAIN AND POISONED CEREAL BAITS BY THE BROWN RAT

By HARRY V. THOMPSON

PART 1. PLAIN BAITS

1. INTRODUCTION

WHOLE English wheat was the standard census bait with which most surplus baiting and food consumption work was done (Chs. 4, 6). Manitoba wheat has also been used, but throughout this chapter 'wheat' indicates dry whole English wheat, though not of a standard variety. Because dry wheat was reserved for census baiting, was a scarce commodity, and does not mix evenly with poisons, it was seldom used in poison baits. The recommended bait bases were sugar-meal, moist sausage-rusk, and bread mash. Some experiments were done using soaked wheat as a bait base, but it was not recommended for general use during the war because the M.O.F. preferred not to release wheat for use in rodent control. However, there are certain environments in which the use of soaked wheat is essential. Thus Freeman found that soaked wheat was often the only attractive bait in the difficult conditions of buffer depots (Ch. 4, § 6). In the research tests on bait in Palestine (mainly on *R. rattus*), soaked wheat proved to be a very satisfactory bait base (Ch. 14).

Since most of our generalizations about the feeding behaviour of rats are founded upon their consumption of dry wheat, it was important to know the rat's relative take of different unpoisoned baits in relation to the wheat standard, for the purpose of estimating sizes of populations surplus baited upon these foods, also for deciding what percentage of poison should be included in a bait. The rat's average and peak take of a bait base was compared with its take of wheat by offering each in turn, for several days at a time, to populations of rats and making daily weighings of the amounts consumed. The populations of rats were either kept in outdoor colony cages under semi-wild conditions (but without any alternative food), or were normally occurring infestations (field tests).

In field tests it is not always safe to compare takes of two baits over long periods as one has no accessory check on population fluctuations. Most of the average takes, therefore, are limited to the 3 or 4 days before and after the change of bait base. Where the peak take of either base occurs more than 4 days from the day the base is changed, the average for that base includes the peak and intervening days. After a change from one food to another, the take is often relatively low for the first day or two. These takes are included in the averages, however, as they may be offset by increased consumption on succeeding days and can only be omitted by a rather questionable method of selection which would differ from test to test. The take on the day following a poisoning is frequently either abnormally large or abnormally small and is omitted from averages, as are also takes of non-surplus bait. In a small number of tests immigration seems to have occurred just before or after the change to the second bait. Such instances were shown by a sharply rising daily take of bait, all of which was sometimes eaten. Details of these tests are therefore omitted.

A comparison between the takes of two bases may also be made from the respective peaks, which may be presumed to occur on the nights when the rats are most thoroughly prebaited. Peaks are not entirely reliable estimates of normal feeding capacity, as they are sometimes the result of hunger due to reduced feeding on previous nights; but by using both averages and peaks as methods of comparison a reasonable estimate of consumption can be obtained.

This paper is not concerned with those special habitat conditions under which one of a pair of baits is unacceptable (Ch. 4, p. 273).

2. THE COMPARATIVE TAKE OF WHEAT AND OTHER BAIT BASES

The field results from tests of four different bait bases are given in Table 1.

(*a*) Soaked wheat

The water content of 'dry' wheat varies according to the climate where it is grown, but millable grain is required to contain not more than 17%. Manitoba wheat, which is 'hard', contains less water than English wheat, which is 'soft'. The water content of wheat is 13·4% according to Woodman (1944). When wheat grains are placed in water they absorb it, rapidly at first and then more slowly, until their original weight has increased by about 60-75%. This maximum absorption is reached in about 72 hours and is greater at higher temperatures.

In most of the field tests, the 'soaked wheat' used has been English wheat soaked in water for 12-24 hours and then drained. In those cases where the water uptake of the wheat has been measured, considerable variations have been found: due to length of time of soaking, variations in the technique of individual workers, differences in wheat samples and temperature.

In 47 cases out of 52 where English wheat was soaked for 12-24 hours, the amount of water absorbed was between 35 and 45% of the original weight of wheat (i.e. the percentage of 'dry' wheat in the soaked wheat was between 69 and 74%). Only in three cases was the amount absorbed less than this, and only in two cases was it more. Only two tests have been done using soaked Manitoba wheat, which takes up just over 50% of its weight in water after about 24 hours' soaking.

Table 1. *Comparison between the amounts of wheat and other baits eaten by wild rat colonies in consecutive baiting tests*

Take of dry wheat (g.)		*Relative take of other base*		
Peak	*Average*	*Peak*	*Average*	
(a) Dry and soaked wheat				
235	194	1·51	1·42	English wheat soaked 12–24 hours
105	77	1·33	1·56	
285	218	1·12	1·38	
375	354	1·08	1·07	
Total 1,000	843	1·26*	1·38*	
205	172	1·18	1·32	Manitoba wheat soaked 16–24 hours
295	252	1·22	1·34	
Total 500	424	1·20*	1·33*	
(b) Wheat and 1:1 rusk				
160	146	2·25	1·83	
380	323	1·82	1·73	
270	217	2·43	2·38	
430	359	1·52	1·62	
100	82	1·90	1·93	
Total 1,340	1,127	1·98*	1·90*	
(c) Wheat and bread mash				
305	277	3·48	3·18	
870	656	2·42	2·96	
270	267	3·00	2·75	
520	459	3·02	3·11	
262	232	3·00	2·68	
162	118	3·15	3·21	
335	323	4·12	3·64	
736	720	3·00	2·20	
375	328	2·51	2·72	
375	328	3·79	3·34	
Total 4,210	3,708	3·15*	2·98*	
(d) Wheat and sugar-meal				
1,350	1,194	1·22	1·00	
1,400	1,253	1·18	0·96	
380	374	0·91	0·80	
163	137	1·38	1·18	
1,015	655	0·76	1·05	
Total 4,308	3,613	1·09*	1·00*	

* Calculated from sums of individual observations.

Under field conditions a certain amount of the absorbed or adhering water is always lost, by evaporation or drainage, the amount depending upon the conditions of humidity and temperature and the surface upon which the bait is laid. Tests have shown that this loss may commonly be between 1·5 and 5% in 24 hours and up to 15% under certain conditions. In practice this means that the weight of residues will be underestimated and thus takes of soaked wheat slightly overestimated. However, because of the difficulties of estimating this variable source of error, no further account will be taken of it here beyond remarking that rats were observed to take less cereal when eating soaked instead of dry wheat in spite of the fact that errors due to desiccation tend to obscure the difference.

Since English wheat absorbs about 40% of its weight of water during 12–24 hours' soaking, we should expect rats to eat the soaked and dry wheats in the ratio of 1·4:1 (or 1·5:1 in the case of Manitoba wheat). In practice, both soaked wheats have been eaten in the ratio of about 1·3:1 dry (Table 1). Although the experiments are too few in number to allow a categorical statement to be made, it is possible that brown rats remove less soaked wheat than would be expected from their consumption of dry wheat, perhaps because they waste less when eating the former (Ch. 4, § 15 (*c*)).

(*b*) **Sausage-rusk**

Largely replacing meat in the British sausage during war-time, sausage-rusk is simply unleavened bread, somewhat resembling biscuit meal. It can be obtained in various grades of fineness, and the medium grade used in all these tests is the most suitable for rat baits.

Tests in outdoor cages and field tests have shown that brown rats prefer moist sausage-rusk to dry and, since 2 parts water: 1 part rusk ('2:1 rusk') makes a rather sloppy bait, equal parts by weight of rusk and water have been adopted as a standard bait base. This mash ('1:1 rusk') is made up freshly each day. Several tests in the sewers support the belief that rats eat twice as much 1:1 rusk and 3 times as much 2:1 rusk as they do dry rusk.

The water content of samples of rusk and minced wheat was determined by heating in a water oven to constant weight. The rusk was found to contain 14% of water, and the wheat 15%. 1:1 rusk thus contains 57% water, and to obtain a similar dry weight of food rats would theoretically eat 1:1 rusk and wheat in the ratio 2·0:1. Information about sausage-rusk was kindly supplied by Dr. J. R. Nicholls of the Government Laboratory and has been incorporated in Table 2.

TABLE 2. *Composition of 100 g. 'dry' sausage-rusk as purchased locally*

Water	*Protein*	*Fat*	*Carbohydrate (equivalent starch)*	*Cals.*
14·0 g.	11·0 g.	1·0 g.	68·0	325

The Medical Research Council (1945) states that 100 g. of ground wheat provides 330 cals. The calorific value of 1 g. of wheat is thus 2·0 times that of 1 g. of 1 : 1 rusk. Rats might therefore be expected to eat 1 : 1 rusk and wheat in the ratio of 2 : 1. In two tests on caged populations this was found to be so, and in field tests (Table 1) an approximately similar relationship was found. One test was done in which a choice of 1 : 1 rusk and wheat was followed by wheat alone. It was found that the total 'dry' weight eaten when there were two baits was about the same as when wheat alone was offered: the average daily takes ('dry') were 480 g. of the two together compared with 450 g. wheat alone.

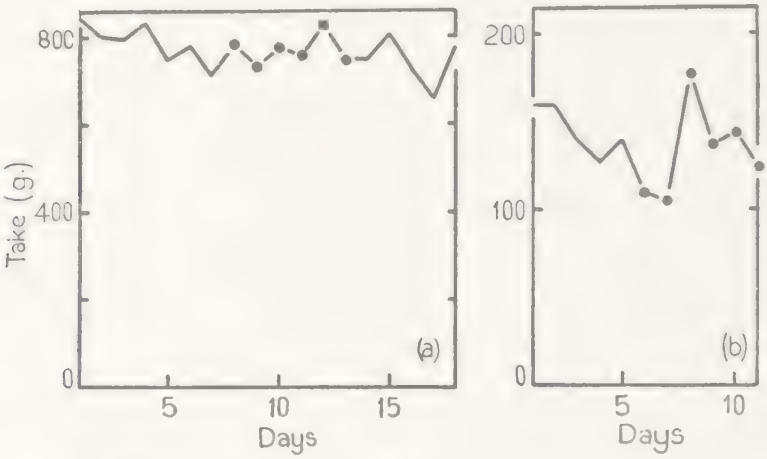

FIG. 1. Takes of wheat and 1 : 1 rusk. (*a*) Thirty-six rats in an outdoor cage. (*b*) Rats in a garden. Takes of 1 : 1 rusk × ½.

The following sample tests illustrate the brown rat's take of 1 : 1 rusk and wheat. In Fig. 1, the daily takes of rusk are plotted × ½ to facilitate comparison with the wheat takes.

Fig. 1 (*a*). The thirty-six wild rats in this cage were fed upon wheat in two P3s for 7 days (peak take 845 g., average take 789 g.), then upon 1 : 1 rusk for 6 days (peak take 1,660 g., average take 1,550 g.), and finally upon wheat again for 5 days (peak take 810 g., average take 746 g.). This test shows very steady takes; the ratio of both averages and peaks is 2·0 : 1.

Fig. 1 (*b*). The rats in this garden were fed upon wheat for 5 days (peak take 160 g., average take 146 g.) and then upon 1 : 1 rusk for 6 days (peak take 360 g., average take 267 g.). The test illustrates the relative drop in take when the base is changed, thus lowering the ratio of averages (1·8 : 1); this is compensated by a slightly inflated peak, which raises the ratio of peaks (2·2 : 1).

(*c*) Bread mash

Many tests in which bread mash was used as a bait base were primarily tests of a poison, the study of relative food takes being incidental. Some dozen tests, while indicating that about 3 times as much bread mash was eaten as wheat, are too incomplete to be produced as decisive evidence.

Bread mash was usually made from fresh or 1-day-old National bread mixed with an equal weight of water ('1 : 1 bread mash') though in practical control measures stale bread was found efficient if not too mouldy. The water content of stale bread was determined as follows. A 2-lb. (930 g.) National loaf cut into halves and kept for 8 weeks was found to weigh 650 g. The bread was then minced into crumbs and its water content, and that of a sample of minced wheat, were determined by heating in a water oven to constant weight. 'Dry' bread crumbs were found to contain 12% of water and the wheat 15%. Day-old bread contains 36% water and therefore 1 : 1 bread mash contains 68% water. To obtain a similar dry weight of food rats would theoretically eat 1 : 1 bread mash and wheat in the ratio 2·7 : 1, which accords reasonably well with the actual observed ratio of about 3 : 1. The water content of fresh National wheatmeal bread is given as 37% by the Medical Research Council (1945), and they also state that 100 g. of this bread contains 250 cals.; while 100 g. of ground wheat contains 330 cals. The calorific value of 1 g. of wheat is thus 2·6 times that of 1 g. of 1 : 1 bread mash.

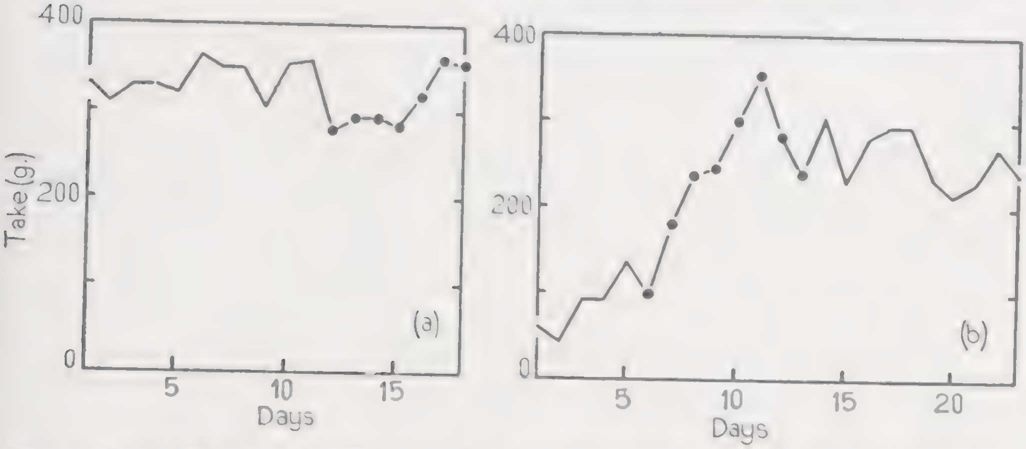

FIG. 2. Takes of wheat and bread mash. (*a*) Twenty-eight rats in an outdoor cage. (*b*) Rats in a confectionery shop, with probable immigration during first 10 days. Takes of bread mash × ⅓.

In some field tests, representative of those in this report, control piles of bread mash were exposed to the air (but not to animals) and daily water loss from draining and evaporation was slight; but under more torrid conditions there would doubtless be some considerable loss in weight.

The following sample tests illustrate the brown rat's intake of bread mash and wheat. In Fig. 2 the daily takes of bread mash are plotted × ⅓ to facilitate comparison with the wheat takes.

Fig. 2 (*a*). The twenty-eight wild rats in this cage included a number of small ones. They were fed on wheat for 11 days (peak take 365 g., average take 337 g.) and then on 1 : 1 bread mash for 7 days (peak take 1,090 g., average take 940 g.). This test illustrates the relative drop in take when the base is changed: resulting in a ratio of averages of 2·8:1, whereas that of the peaks is exactly 3:1.

Fig. 2 (*b*). After 17 days of feeding upon surplus wheat, during which the takes fluctuated, the rats at this baker's shop took gradually increasing amounts of wheat, up to 135 g. on the twenty-second day. On changing the bait to bread mash there was a steady rise to a peak of 1,060 g. on the sixth day, falling to 720 g. on the eighth. The average take for the last 4 days of bread mash baiting was 882 g. and on returning to wheat baiting the takes remained at a comparatively high level (peak 305 g., average first 4 days 277 g.). This test shows that an influx of rats (possibly emanating from a sewer, for these premises were very liable to such invasions) took increasing amounts of bread mash until a peak was reached, after which relative takes of wheat and bread mash remained steady. The bread mash peak, possibly because of hunger among the new arrivals, is a good deal higher than that of wheat (3·5:1) and also raises the ratio of averages (3·2:1).

(*d*) Sugar-meal

The water content of samples of sugar-meal (1 part sugar to 9 parts wheatmeal) and of minced wheat was determined by heating in a water oven to constant weight. The sugar-meal was found to contain 14% of water, and the wheat 15%. To obtain a similar dry weight of food rats would theoretically eat sugar-meal and wheat in the ratio 1·0:1.

According to the Medical Research Council (1945) 100 g. ground wheat provides 330 cals., while 100 g. flour (85% extraction, fortified Calcium) provides 343 cals., and 100 g. castor sugar provides 380 cals. The calorific value of 1 g. sugar-meal is thus 347 or 1·05 times that of 1 g. wheat.

There have been a few cases in the field where rats have refused to eat sugar-meal, or eaten it very sparingly. This can usually be attributed to 'shyness' or to conditioning to an already abundant food supply (which introduces problems not relevant to the present chapter). The following sample tests illustrate the brown rat's take of sugar-meal and wheat under conditions where both are acceptable.

Fig. 3 (*a*). The nine rats in this cage were fed upon wheat for 7 days (peak take 315 g., average take 286 g.), then upon sugar-meal for 7 days (peak take 260 g., average take 229 g.). The rats were then fed upon wheat again for 7 days (peak take 320 g., average take 256 g.). These rats took consistently less sugar-meal than wheat, and the ratio of both averages and peaks is 0·8:1.

Fig. 3 (*b*). The rats infesting this hedge-bank were given a surplus of wheat for 7 days (peak take 1,350 g., average take 1,194 g.), then sugar-meal for 7 days (peak take 1,650 g., average take 1,199 g.), and finally wheat again for 7 days (peak take 1,400 g., average take 1,253 g.). This test shows a drop in take on changing from wheat to sugar-meal, compensated for by a high sugar-meal peak 3 days later. The ratio of peaks was 1·2 : 1, and that of averages was 1 : 1.

3. DISCUSSION

There is little or no mention in the literature that rats eat more of a wet than a dry bait, and without taking this into consideration any table of bait preferences is invalid. Early experiments with bread mash and other wet bait bases suggested that rats ate approximately the same 'dry equivalent' of different cereal foods within the normal range of palatability (i.e. if food *A* contained 50% water and food *B* none, rats ate twice as much of *A* as of *B*). However, all our standard baits were derived from wheat and, as might be expected, their calorific content varies inversely with their water content. For these baits, then, the term 'dry equivalent' is synonymous with relative calorific content, but it does not follow that this would hold good for baits derived from another cereal or for non-cereal baits. Our choice of bait bases was restricted by the war-time shortage of food (especially those rich in protein), and also by the necessity for popularizing the use of a few standard bait bases in order that research might be concentrated upon them and the results quickly and universally applied to practical rat destruction. More work upon the calorific and water content of a wider range of baits would yield valuable results; but it does not follow that the bait base with the highest calorific content or, alternatively, with the highest water content, will be a good foundation for a successful poison bait. It is not known whether or not wild rats usually succeed in obtaining a diet containing satisfactory amounts of all the desirable food factors, and those in short supply must surely vary from one infestation to another, thus influencing the bait preferences of those rat populations.

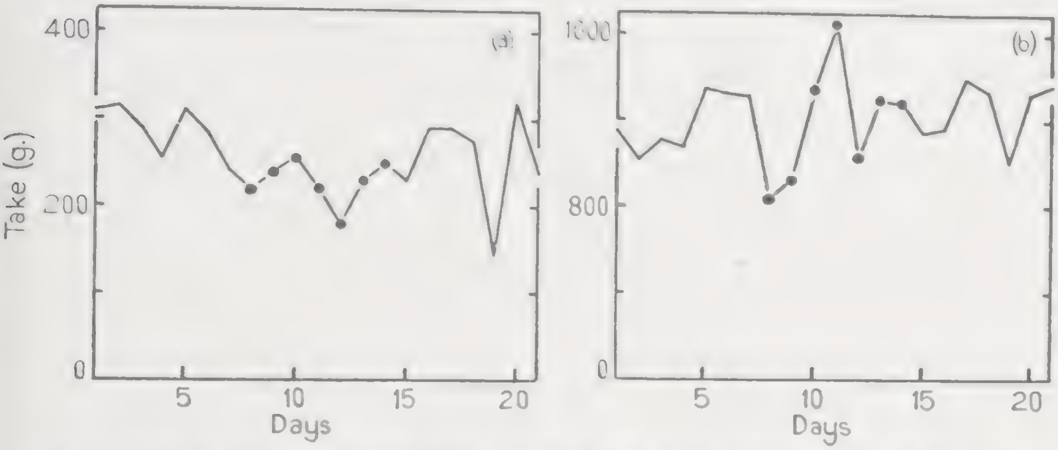

Fig. 3. Takes of wheat and sugar-meal. (*a*) Nine rats in an outdoor cage. (*b*) Rats in a hedge-bank.

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4. SUMMARY

1. The brown rat's take of wheat was compared with that of the standard bait bases: soaked wheat, sausage-rusk and water (in equal parts by weight i.e. '1 : 1 rusk'), '1 : 1 bread mash', and sugar-meal. Wheat and the base to be tested were offered in turn, for several days at a time, to populations of rats and the daily takes were recorded.

2. It was found that the rats ate on the average $1\frac{1}{3}$ times as much soaked wheat as they did wheat, twice as much 1 : 1 rusk, 3 times as much 1 : 1 bread mash, and an equal amount of sugar-meal.

3. Calculation of the water contents and calorific values of the bait bases showed that, roughly, the former was in direct and the latter in inverse proportion to the amounts eaten. Thus, if the average wheat consumption per rat per day is 24 g. (Ch. 6) the average consumption of soaked wheat, 1 : 1 rusk, 1 : 1 bread mash, and sugar-meal would be respectively, 32, 48, 72, and 24 g. per day.

PART 2. POISON BAITS

5. INTRODUCTION

In the first part of this chapter it has been shown that brown rats, surplus baited in the wild, or in cages, eat more of a wet cereal base than of dry wheat or sugar-meal, and that the amounts eaten are approximately in inverse proportion to the dry cereal content of each base. When a poison bait is given, very much less is eaten because of the onset of illness, but wet poison baits are still eaten in greater amounts than dry ones. Accurate measurement of the takes of various poison baits would give information about feeding behaviour, influence of the baiting system, and acceptability of the poison baits under different conditions. The present data are insufficient for final conclusions but suggest several points that might profitably be investigated. I am indebted to Mr. P. H. Leslie for statistical and other advice in the treatment of the following data.

6. EXPERIMENTS

(*a*) **Nature of the data**

Between December 1941 and May 1942 most poisonings were preceded by surplus prebaiting in containers, and daily takes of plain and poison baits were measured. After that time prebait and poison bait were usually placed in rat holes, where measurement is impossible, and most of the later information about take of poison bait comes from tests in large outdoor cages. The majority of takes of poison are the result of a single day's feeding, but in a few cases bait was left down for 2 days. The second day's take was invariably small or nothing. The data available for analysis are thus limited to early and often imperfect field trials, to cage tests, and a far from random sample of different poisons and bases. It would have been preferable to reject all but a small number of thoroughly reliable trials and to have carried out a further series of comparative tests on populations large enough to eliminate some of the evidently chance results in the present data. Since this course was not open to us it was decided to make no selection of the data beyond rejecting the more unsuccessful tests and those on populations which took less than 80 g. wheat prebait (i.e. representing 3–4 rats only).

A successful test has been defined in Chapter 4 as one that kills 85–100% of the population, but in order to increase the data for our analysis we have been obliged to relax this criterion slightly. All tests are omitted which killed less than 80% of the population except that when barium carbonate was used 60% was taken as the lower limit because there were comparatively few good kills with this poison. Tests done on previously treated populations or with inadequate concentrations of poison are not used. Several tests are included in which the error in measurement of poison bait is undoubtedly large. The analysis therefore covers a much wider range of take than would be expected in tests specifically designed for studying poison takes, and certain real differences may have been obscured.

Percentage success is derived from a comparison of the peak in the first census or surplus prebaiting with that in the second to fifth days of postbait. In a few cases the peaks cannot be determined with certainty because of insufficiently long baitings, but probably only slight errors are involved.

With the wide variety of habitats included in these tests the peak takes of wheat or other prebait are not strictly proportional to the populations; for, except in the cage tests, varying amounts of alternative food may have been included in the diet. It can be assumed, however, that the rats were at least feeding very largely on prebait and that the peak takes afford a reasonable basis for comparison of population size.

(*b*) Influence of the base

Experiments with marked rats have shown that only a small part of the night (generally less than 4 hours) is spent in feeding on surplus baits of wheat (Ch. 4, Table 32). Consequently there is plenty of time for the more watery bases to be ingested at the same rate but over a longer period. If wet and dry baits were eaten at the same rate it would be expected that the take of poison at a given concentration would be the same whatever the base—unless the onset of illness is slower with some bases than others. While there may be some such delaying effect with certain bases the difference is probably insignificant in comparison with the concentration of poison in the stomach. Thus from the moment the rat starts feeding a limit is set to the time it can continue to ingest poison baits, depending on the speed with which that poison produces hesitation and refusal (Ch. 8), and in the main, irrespective of the nature of the base.

If this argument is accepted it follows that with a certain concentration of poison, the observed greater take of wet poison baits indicates that they are eaten more rapidly than dry baits. However, the comparative speed of feeding on different baits is not necessarily related to the total amount of each eaten in 24 hours. Thus, suppose it is found (see Part 1) that during the first of three consecutive periods a population eats 1 kg. wheat per day, that on each of the next few days 2 kg. rusk and water are eaten (1 : 1 by weight) and then 3 kg. bread mash per day, it does not necessarily follow that the amounts eaten during the initial feeding stages, e.g. the first half-hour each night, are in the ratio 1:2:3. Similarly, flour, sugar-meal, and wheat are not necessarily eaten at the same speed, though the overnight takes may be the same when these baits are offered in turn to the same rats.

(i) *Miscellaneous studies.* Speed of feeding has been studied in four ways: by measuring the take after fixed intervals from the start of feeding, watching marked rats, stomach analysis, and measuring the take of poison bait in relation to that of plain bait. The first two methods can be used not only for rats feeding on poison baits but also on plain and, unlike the others, can therefore be applied more than once to the same population. Such data are more strictly comparable than when different populations are involved.

Rats token baited on wheat and later on 1:1 rusk were found to eat almost twice as much of the latter in the first half hour (Ch. 4, Table 34). Other rats were watched taking 1:1 rusk and were found to be eating it at about the same rate as they had eaten wheat; consequently there was no greater take of this wet base with poison than could have been expected if wheat had been used (Ch. 4, Table 32). The stomach contents of poisoned rats are much smaller when sugar-meal is the base than when rusk has been used; but exactly comparable data are difficult to obtain because of the variety of other factors affecting intake in the populations studied by this method.

(ii) *Takes of wet and dry poison baits.* It had been hoped in the present paper to be able to give accurate data on the difference in poison take according to the base used; but unfortunately there are comparatively few observations on any one bait except sugar-meal and arsenic and thus a direct comparison cannot be made of the take of each poison bait in relation to that of wheat. An average has therefore been taken for all dry baits, which shows that where surplus prebaiting and poisoning is preceded by a wheat census about 10% as much poison bait is eaten as wheat.

It is less justifiable to take an average for all wet baits since the water contents are considerably more variable than with the dry baits, but as there are only twelve observations and they concern several bases and poisons, such an average is the best that can be done. As a percentage of the wheat peak the average take of all wet poison baits is 21%, indicating that takes were about twice as high when a wet bait was used instead of a dry one. Little importance attaches to the actual size of this figure, which would vary according to the proportion of the total made up by baits of the different water contents.

(*c*) Takes of prebait and poison bait

Although only twenty-nine out of the forty-eight surplus prebaiting tests were preceded by a wheat census, almost all include data on the peak take of prebait. The take of poison bait can therefore be expressed in terms of this quantity. The regression of log take of poison bait on log prebait peak gives

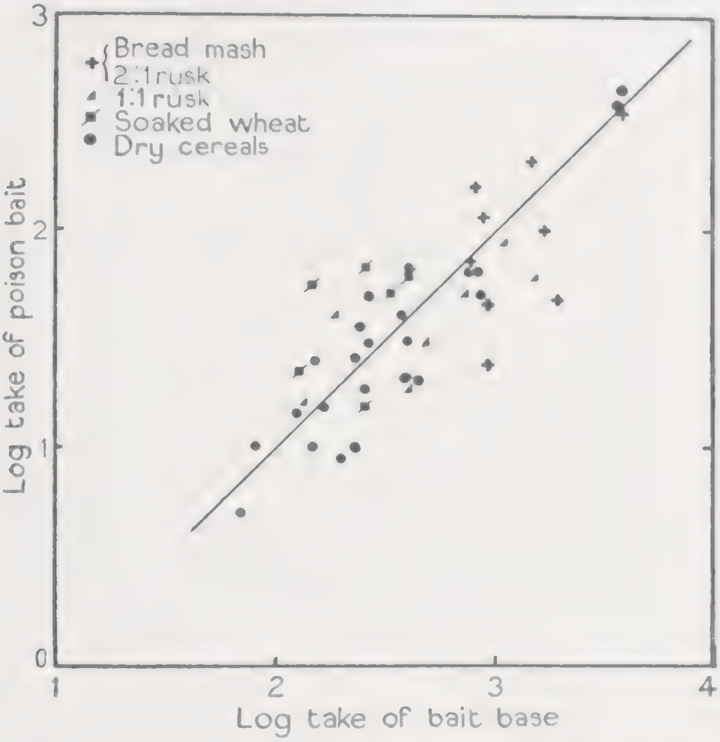

FIG. 4. Relationship between the takes of plain and poisoned cereal baits.

$b = 0{\cdot}8231 \pm 0{\cdot}0843$ (45 observations). Since this regression coefficient only just differs significantly from unity at the 5% level it has been assumed for simplicity that $b = 1$ and that the takes:

$$\frac{\text{poison bait } (P)}{\text{prebait peak } (B)} = C_1 \text{ a constant.}$$

These observations have been plotted in Fig. 4 according to the class of base. It is seen that most bases are distributed fairly symmetrically about the regression line with $b = 1$ but that with soaked wheat there is a tendency for takes to be higher than the expected value. This suggests that per gramme cereal content, soaked wheat is eaten more rapidly than the other bases; but a critical examination of the field conditions does not enable us to assert this with great confidence. Some of the populations were rather small, and others had such an abundance of natural food that prebait takes may have been relatively low. A more careful study is undoubtedly called for as it is known that soaked wheat proves attractive when other bases do not (Ch. 4); but at present it is felt that there is not sufficient evidence for abandoning the assumption that $P/B = C_1$, a constant for all bases.

Neglecting differential effects of the bases we may now examine the data for any differences in take according to the poison used. It is better to work with logs as the distribution log P—log B appears to be much more symmetrical than that of P/B; therefore if log P—log $B = z_1$ we have the following:

Poisons	*No. observations*	$\bar{z}_1$
Zinc phosphide	7	−0·9687
Fine arsenic	11	−1·0143
Medium+1 coarse arsenic	11	−1·0340
Barium carbonate	4	−0·9016
Red squill (powder+extract)	8	−1·2189
Alpha-naphthylthiourea	3	−0·7787
Thallium sulphate	1	−0·7812
Total	45	−1·0175

The analysis of variance for comparing these poisons in between themselves is:

	Sum of squares	*Degrees of freedom*	*Mean square*	*Variance ratio*
Between poisons .	0·62480	6	0·10413	. .
Remainder . .	2·18946	38	0·05762	1·81
Total. . .	2·81426	44	. .	. .

For 6 and 38 degrees of freedom the 5% point of the variance ratio is 2·36 approximately; so that there is no evidence of any difference between the poisons.

The grand mean of the forty-five observations is −0·0175±0·0381 and the ($P = 0{\cdot}95$) range is −1·0937 to −0·9413.
Hence, taking antilogs

$$\frac{P}{B} = 0{\cdot}096 \qquad \text{(range 0·081 to 0·114).}$$

From this analysis we may conclude that the data show no significant difference in take whatever the poison used and that about 10% as much poison bait is eaten as plain prebait.

Our evidence so far about takes of poison baits after surplus prebaiting may therefore be summarized as follows: (1) In relation to population size (i.e. to peak take during census baiting with wheat) rats eat more of a poison in a wet than a dry bait, but the data are not sufficient to prove how much more. (2) In relation to the base used for poisoning, about 10% as much poison bait is eaten as plain; but when soaked wheat is used takes may be rather higher than average. (3) When offered in succession, plain prebaits are eaten in amounts inversely proportional to their cereal contents. Poison baits are thus also eaten in greater quantities, i.e. more rapidly the lower their cereal content. (4) These are empirical data and will not necessarily apply to baits with higher water contents or to types of bait other than those studied.

Now when the take of one poison is to be compared with that of another a correction must be made if a different base was used in each case. Our analysis has shown that these factors are at least approximately the same as those used in comparing takes of different prebaits, though there is no *a priori* reason why this should be so. Thus for comparing the takes of poison, those used in bread mash and 2:1 rusk are divided by three, in 1:1 rusk they are halved and in soaked wheat reduced to their content of 'dry' wheat and poison. Takes of poison in all 'dry' cereal baits are considered comparable to those with wheat, though the evidence has only been analysed for prebaits of sugar-meal

(*d*) Takes of wheat and poison bait

In order to test the effect of this correction for water content we may now carry out an analysis similar to that in the preceding section but comparing peak takes of wheat with corrected takes of poison bait. If W = wheat peak and P = take of base, corrected where necessary, then for $\log P - \log W = z_2$ we have the following:

Poisons	*No. observations*	$\bar{z}_2$
Zinc phosphide	6	−1·2490
Fine arsenic	5	−0·9835
Medium arsenic	8	−1·0828
Barium carbonate	3	−0·9203
Red squill (powder+extract)	3	−1·1439
Alpha-naphthylthiourea	3	−0·8736
Thallium sulphate	1	−0·9622
Total	29	−1·0638

The analysis of variance for comparing these poisons in between themselves is:

	Sum of squares	*Degrees of freedom*	*Mean square*	*Variance ratio*
Between poisons	0·44084	6	0·07347	. .
Remainder	1·05989	22	0·04818	1·53
Total	1·50073	28	. .	. .

The 5% point of the variance ratio for 6 and 22 degrees of freedom is 2·55, so that there is again no evidence of any difference between the poisons considered. The mean of the twenty-nine observations is −1·0638 ± 0·0430 and the range ($P = 0{\cdot}95$) is −1·1519 and −0·9757

$$\text{taking antilogs } \frac{P}{W} = 0{\cdot}086 \qquad (\text{range } 0{\cdot}070 \text{ to } 0{\cdot}106).$$

Since this result is not significantly different from that already found for the relationship between takes of prebait and poison bait, we may conclude that the correction for water content is at least a suitable working hypothesis, though it should be pointed out that as two-thirds of the test were with dry baits the analysis is not a reliable proof of the validity of our correction factors. However, the importance of this analysis is more than that of a check on this point since we need these data for a comparison with the results of token baiting, where there are no figures for an analysis of the first type because takes of surplus prebait are not available.

(*e*) Effect of token baiting

Twelve tests of token baiting are available for a comparison with the twenty-nine where surplus baiting followed the wheat census. Calculating $\log P - \log W = z_3$ as before, we find the mean value to be −0·8497, of which the antilog is 0·1413.

Poisons	*No. observations*	$\bar{z}_3$
Zinc phosphide	2	−0·8802
Fine arsenic	3	−0·9070
Medium arsenic	1	−0·8931
Barium carbonate	4	−0·5550
Red squill extract	1	−1·0580
Alpha-naphthylthiourea	1	−0·9890
Total and grand mean	12	−0·8497 ± 0·0463

The difference between $\bar{z}_3$ and the corresponding value $\bar{z}_2$ for poison takes after surplus baiting is −0·2140 ± 0·0734 and $t = 2{\cdot}92$. Since there are 39 degrees of freedom this difference is significant ($P = < 0{\cdot}01$). Thus after token baiting a greater amount of poison bait is consumed, the corrected take in relation to the wheat peak being 14% compared with 8·6% after surplus baiting.

As a further check we may consider zinc phosphide and arsenic only, since takes of barium carbonate after token baiting are rather higher and include one bait at 10% (though analysis of variance shows that there is no significant difference between poisons). For zinc phosphide and arsenic:

$$\begin{array}{lrll} & & & \textit{antilog} \\ \text{Surplus:} & \bar{z}_2 = & -1{\cdot}10917 \text{ (19 observations)} & 0{\cdot}078 \\ \text{Token:} & \bar{z}_3 = & -0{\cdot}89577 \text{ (6 \quad ,, \quad)} & 0{\cdot}127 \\ & & -0{\cdot}21340 \pm 0{\cdot}0844 & \\ & t = & 2{\cdot}53 & \\ & d.f. = & 23 & \\ & P = & < 0{\cdot}02 & \end{array}$$

which is a similar result but with fewer degrees of freedom. From the antilogs we find that with these two poisons the comparative takes after surplus and token baiting were respectively 7·8 and 12·7% of the wheat peak.

7. DISCUSSION

(*a*) General

In all our experiments the take of poison bait has been considerably lower than the daily take of prebait. The most obvious explanation is that illness and death prevent the rats from continuing to feed for the same length of time as they do on plain bases. It is unnecessary to assume that there is any discrimination of the poison before the onset of illness. Rats were also found to eat a significantly greater amount of poison bait after token baiting. Hunger undoubtedly increases the speed of feeding on plain bases and may be the chief factor responsible for the higher take of poison bait after token baiting in the present tests. The only experimental evidence of the effect of hunger on the take of poison bait is as follows. Eight rats in an outdoor cage were given only half their daily food requirements: 50 g. wheat and 40 g. sugar-meal, the latter placed beside the entrance to the nest box. After 3 days, 5% zinc phosphide was included in the sugar-meal and a surplus of wheat was put in the feeding tin. These rats ate 25 g. poison bait or 13·9% of their peak take of wheat. Further tests of this nature are needed; but though such evidence might show that the take of poison bait can be increased by hunger this is not necessarily the explanation of the field results. It has frequently been observed that rats in corn-ricks or on well provisioned farms take poison baits during the day-time in a similar manner to that of token-baited rats known to be hungry. It cannot be proved that such rats take particularly large amounts of poison bait, but this day-time response is not caused by hunger and may be because of a liking for a bait not previously available in excess: for surplus-baited rats rarely feed in the day-time. It is not to be expected that all token-baited rats will take large quantities of poison bait. Apart from differences in hunger and bait preference, there is always the possibility of interruption; especially during day-time feeding.

Laboratory evidence shows that the time of onset of illness varies according to the poison. Therefore, if feeding in the wild were randomly distributed throughout the night the relative amounts of poison bait eaten would decrease in the order barium carbonate, medium arsenic, fine arsenic and zinc phosphide (Ch. 8). The data do, in fact, suggest that this may be so; but if future work confirms the present conclusions that this is of no statistical significance then it must be assumed that differences in the times of onset of illness with these poisons are not important under some field conditions. Suppose, for example, there is a short initial burst of feeding followed by an interval during which the rat felt ill, then theoretically the same average amount of a given base would be eaten irrespective of the kind of poison and the time of onset of illness.

(*b*) Efficiency in relation to concentration of poison

The percentage of a population killed in a field trial is probably related to the mean take of poison bait and the dispersion of the individual takes. A success could result from a low mean with a small dispersion and a failure from a higher mean with a greater dispersion. It is because this variation is unpredictable that the optimum poison content of a bait cannot be determined from laboratory tests alone.

Since the average take of wheat or sugar-meal per rat per day is 24 g. the average take of poison bait is roughly 10% of this, i.e. 2·4 g. in sugar-meal, 3·4 g. on soaked wheat, 4·8 g. in 1:1 rusk, or 7·2 g. in bread mash or 2:1 rusk. In Table 3 various poison contents of these weights of bait are calculated to show relative toxicity in terms of L.D. 50 for white rats of 220 g. body weight. (This is the average body weight for certain wild rat populations; Ch. 6.)

By considering the mean take of poison bait after surplus baiting (10% of prebait peak) instead of after token baiting (14% of peak take of wheat) we are underestimating the takes that might be expected in practice. The important feature of Table 3, however, is the relative take of poison according to each formula and this could equally well have been calculated from the number of L.D. 50 in purely arbitrary units of bait. The selection of 2·4 g. as our unit of bait is useful in showing very roughly the average take of poison and it is seen that some of the baits in common use contain a very high dose, e.g. 3·4 g. soaked wheat with 5% zinc phosphide contains 19 L.D. 50 in terms of mg. per average rat. Since the actual size of this and the other doses is obtained from a number of approximations we shall not discuss whether or not they could be expected to kill 85% or more of a wild population, but shall at first regard them as arbitrary units of relative toxicity for white rats.

We have next to consider whether these units can be expected to bear a relationship to the results of a field poisoning. Firstly, it is necessary to assume that brown rats are susceptible to each poison in about the same ratio as was the white rat stock used for the determination of L.D. 50. We have experimental evidence of this for medium arsenic, where a toxicity test on brown rats showed that the L.D. 50 was about the same, or perhaps slightly lower, than it is for white rats, but we know little about brown rats' susceptibility to the other poisons. Thus some might prove more toxic and others less, with the result that the ratios between the various L.D. 50 would be appreciably different from those for white rats.

TABLE 3. *Poison content of average take of various baits (No. of L.D. 50 per average rat)*

Bait base	*Av. wt. of bait eaten (g.)*	*α-naphthylthiourea*	*Zinc phosphide*		*Fine arsenic*		*Medium arsenic*		*Red squill powder*	*Red squill extract*	*Barium carbonate*
		2%	2%	5%	5%	10%	10%	15%	10%	10%	20%
Sugar-meal	2·4	53·3	5·2	13·0	4·5	9·1	5·8	8·7	2·6	..	3·1
Soaked wheat	3·4	74·7	7·3	19·0	6·3	12·7	8·1	12·2	3·6	5·2	4·3
1:1 rusk	4·8	106·7	10·4	26·1	9·1	18·2	11·6	17·4	5·1	7·4	6·2
Bread mash or 2:1 rusk	7·2	160·0	15·7	39·1	13·6	27·3	17·4	26·1	7·7	11·0	9·3
L.D. 50 mg./kilo.*	..	4·2	41·3		119		186		420	297	700
L.D. 50 mg./220 g.	..	0·9	9·1		26·2		40·9		92·4	65·3	154

* Some of these values are slightly different from those in Chapter 2.

Secondly, in a field test an efficient poisoning is required to kill not 50% but 85–100% of a population. It might therefore have been better to express our arbitrary units in terms of L.D. 85 or higher in order to correct the ratios for any differences in the slope of the regression lines for the different poisons (as a result of which the L.D. 50 would not bear a constant relationship to the doses giving more than 50% mortality). However, apart from the much greater error attached to such figures, the differences between a toxicity test and a field experiment are so great that there would probably be but little advantage in using them. Not only are field conditions highly variable, but wild rats do not all take a graded dose according to body weight (though there may be an average relationship, Ch. 9), and as has been shown for medium arsenic there is probably a very much greater range of susceptibility within and between wild populations than within a stock of white rats (Ch. 2, Appendix 1). We shall assume, therefore, that in comparison with these other variables, L.D. 50 is as good a rough index of relative toxicity as for example L.D. 85.

We now have to examine the efficiency of the baits in the field to see whether the results bear any useful relationship to our arbitrary units of toxicity. With fine and medium-particle arsenic, poor results are obtained with dry baits containing 5% and 10% respectively. Such baits contain 4·5 and 5·8 units of toxicity in an average dose. The successful baits with arsenic are soaked wheat with 10% medium arsenic (8·1 units), sugar-meal with 15% medium arsenic (8·7 units), sugar-meal with 10% fine arsenic (9·1 units), and all the wetter baits. With this poison there is thus a critical level of concentration between 6 and 8 units per average take.

With squill powder at 10% in 1 : 1 rusk an average dose contains 5·1 arbitrary units and the following per cent. kills were obtained (Ch. 4, Table 51 (*c*)): 100, 96, 94, 89, 83, 83, $\leq$ 85. It was also used at 10% in bread mash and 2:1 rusk and at 15% in 1:1 rusk, all these formulae containing 1½ times the strength of squill in an average dose (7·7 units). Here the results were: 100, 100, 100, 100, 100, 99, $\leq$ 85% kill. Because of different colony sizes and baiting systems we do not know whether to attach equal weight to the tests in the two groups but the higher proportion of failures at 10% in 1:1 rusk certainly suggests that this concentration may be below the critical level.

This indication is borne out by the tests in which squill powder was used with sugar added to 1:1 rusk, the results of five trials being as follows: 86, 79, 78, 72, 55% kill. It was difficult to explain these inferior results in terms of the effect of sugar, and it seems probable, in the light of the analysis above, that they may have been chance results from a dangerously low concentration of squill powder in 1:1 rusk. (Moreover it is possible that squill powder is taken less readily than squill extract or the other poisons (Fig. 4) although, because of the scarcity of our data, we have considered the two forms of squill together.) The squill extract prepared commercially and used at 10% in 1:1 rusk proved efficient in the field, while at 5% it failed (Ch. 4, Table 51 (*d*)). The successful concentration contains 7·4 units. There were also some failures with laboratory extracts made by the Bureau and used in 1:1 rusk at a strength equivalent to that of 10% powder (5·1 units), so that we find a critical level between 5 and 7 units.

Barium carbonate has only been used in bread mash and the average take contains 9·3 units. There is some evidence that, at least when used in containers, this bait is not reliable. However, in the sewer campaign sponsored by the M.O.F. it appears to have been efficient and it must be admitted that final proof of its possibilities is not available (Ch. 4, § 11 (*f*)).

Zinc phosphide has proved efficient at 5% in sugar-meal and 2% in 1:1 rusk but has not been tested at a concentration where failures resulted. With alpha-naphthylthiourea, the concentration of poison in any 2% mixture seems unnecessarily high, but the one test at 1% in 1:1 rusk was a failure. However, this may have been because of the difficulty of mixing the poison evenly through the bait base, for at 2% in sugar-meal good results were obtained.

Table 4 shows the relationship between the units of toxicity and success or failure of baits in the field.

With arsenic, squill powder and extract it may be concluded that there is a critical level at about six to seven arbitrary units of poison below which baits begin to give unreliable results. Although no practical recommendations can be based on this list a number of research projects are suggested: (1) the efficiency of barium carbonate in surface and hole baiting should be examined; (2) the present recommendation for using squill powder at 10% in 1:1 rusk may be incorrect and a 15% concentration should be tried; (3) 10% squill extract is evidently very close to the critical level, and while no serious failures occurred in general habitats there was one bad failure in a corn-rick which is not easily explained (Ch. 4, p. 232). Squill extract should therefore be tried at 12½% or 15%; (4) tests should be made of zinc phosphide at 2% on soaked wheat. The same reduction for sugar-meal baits might not be efficient as this would bring the poison take below the critical level deduced from the other poison baits; but it would be of great theoretical interest to do such tests. It would be unwise to predict the critical level for zinc phosphide and other poisons, not only because of the many assumptions and approximations in the calculations, but because the take of bait might be increased with reduced concentration (Ch. 8, Appendix 2).

TABLE 4. *No. of units of toxicity (L.D. 50 per average rat) in an average take (2·4 g. dry cereal content)*

	Insufficient units		*Sufficient units*			
Alpha-naphthylthiourea . .	53·3 (in 1 : 1 rusk)		53·3 (in sugar-meal)			
Zinc phosphide . . .	..	..	10·4	13·0	19·0	&c.
Arsenic	4·5	5·8	8·1	8·7	9·1	&c.
Squill powder . . .	..	5·1	7·7	..	..	
Squill extract . . .	3·7	5·1	7·4	..	..	
Barium carbonate . . .	..	9·3	..	..	..	

(*c*) Population size and take of poison bait

Where census baiting would have ruined the purpose of certain tests the only indication of the size of the original population is the amount of poison bait eaten. The present data show clearly enough that any estimate of potential wheat take from the poison take would be subject to very great error in any one case. However, where only minimum feeding capacity needs to be known, estimates are less open to objection. Where zinc phosphide, arsenic, or squill was used the takes were very seldom more than 20% of the peak take of prebait or of wheat. It would therefore be expected that with these poisons the feeding capacity of a population could be estimated as greater than 5 times its take of poison bait. With barium carbonate and possibly alpha-naphthylthiourea a similar estimate would less often be conservative.

Twelve surplus-baited tests in outdoor cages, where the number of rats is known, give us an opportunity of estimating the populations from their poison takes and checking these estimations against the known figures (Table 5). The expected prebait peaks were obtained by multiplying each poison take by 10; the minimum feeding capacity is half this value. A division of the expected wheat peaks by 24 (the average daily consumption of dry cereal bait by the average rat) gives the estimated numbers of rats. Fairly good agreement was found with those actually present except in two instances, where the actual numbers were considerably higher. The estimated minimum number of rats (i.e. half that expected) is thus very conservative.

TABLE 5. *Take of poison bait as a measure of population size in outdoor cages*

Poison	*Base*	*Take (g.) of poison bait*	*No. of rats*	
			Observed	*Expected**
Arsenic	dry	15	5	6
,,	,,	30	12	12
,,	,,	18	6	7
,,	,,	8	5	3
,,	,,	10	3	4
,,	,,	10	5	4
,,	,,	20	14	8
,,	,,	20	11	8
Zinc phosphide	,,	10	4	4
Total	,,	141	65	56†
Arsenic	wet (1:1)	40	5	8
Squill powder	,, (2:1)	23	10	3
,,	,, (2:1)	45	9	6
Total	,,	..	24	17

* Calculated from $\frac{P}{F} \times \frac{10}{24}$ where P = take of poison bait (g.) and F = correction factor for added water (*1* for dry bases; *2* for 1:1 rusk; *3* for 2:1 rusk).

† From sum of takes.

8. SUMMARY

1. Wet poison baits were eaten in greater quantities than dry baits relative to the population size. Because illness sets a limit to the time feeding can continue it follows that the rate of ingestion of wet poison baits is higher than that of dry poison baits.

2. In forty-eight tests in which rats were fed upon a surplus of food throughout, the take of all poison baits was found to be 2·6 to 39·3% of that of the peak take of the prebaits, or of the wheat used in preliminary census baiting: in the latter case after correcting for any differences in water content of poison bait and wheat. Over four-fifths of the takes of poison bait were between 4 and 16% of these peaks and the mean for all tests was about 10%.

3. In twelve tests with various poisons, the rats were fed a surplus of wheat followed by 2–4 days of a 'token' amount of the bait base in which the poison was finally offered. The poison bait take was found to be from 8·7 to 32% of that of the peak take in the census with wheat (again after correction for water content) and the mean of these tests was about 14%.

4. The amounts of poison bait eaten by token-baited rats were found to be significantly higher than those eaten by surplus-baited rats.

5. No significant difference between the takes of the different poison baits could be established; but this may well have been due to the inadequacy of the data. These calculations were carried out after correcting for differences in take attributable to the base. Except in one or two cases baits with a concentration of poison below that used in current practice, have not been included.

6. The concentration of poison to be used in a base can only be decided empirically from the results of field trials. It appears, however, that with arsenic, squill powder, and squill extract, the average take of bait should contain over six or seven L.D. 50 in terms of mg. per average rat. At lower concentrations there may be fairly large numbers of survivors among the rats which take less than average amounts.

7. When census baiting is not carried out the take of poison bait may, in successful cases, be used to find the amount of wheat which the rats might have been expected to take. The minimum expected quantity is generally 5 times the take of poison bait after correcting for differences in water content.

8. From this potential wheat take the minimum number of rats eating the poison can also be obtained, using the conversion factor of 24 g. wheat per rat per day. In cage tests the minimum estimate is very conservative and better agreement is obtained by calculating the expected wheat consumption as 10 times the take of poison bait.

REFERENCES

Medical Research Council (1945). 'Nutritive values of wartime foods.' M.R.C. War Memo No. 14. 59 pp. London, H.M.S.O.

Woodman, H. E. (1944). 'The composition and nutritive value of feeding stuffs.' Bull. Minist. Agric. No. 124. 24 pp. London, H.M.S.O.

8

THE BEHAVIOUR OF WHITE RATS TOWARDS POISON BAITS

By J. RZÓSKA

I. INTRODUCTION

BEFORE a poison bait is consumed the rat's approach to it is governed mainly by factors of behaviour; but a new phase is begun with the first morsel eaten: for the action of the poison creates discomfort or illness of varying strength. It is important to know how long it is before symptoms arise; what their relations are to the nature and dose of the poison, and how feelings of discomfort and illness influence behaviour. Two phases of behaviour could usually be recognized, first a 'hesitation' period which later developed into 'refusal'. Tests on the onset of these 'warning symptoms' were performed mainly on white laboratory rats by means of a feeding method.

2. METHODS

Each animal was kept for some days before each test in a separate cage with adequate water supply and normal food. Before an animal could be tested it had to be conditioned to accept small pieces of plain bread paste, the future poison base, given by hand or on a stick. Bread paste was prepared by mixing fresh or stale bread with water and kneading it into a stiff paste. All disturbing influences such as fear, an unfamiliar food or environment, had to be excluded. Usually a small group of rats was taught at once; a lump of bread paste was offered some days before so as to make the animals familiar with the food, and 6–10 hours' starvation was imposed before conditioning started. Each animal was offered a small piece of bread paste through the wires of the cage; at first it took some time before the animals accepted the bait. Careful sniffing was observed and a great display of individual differences; but with most of the white rats there were no difficulties, and after 1–3 days they reacted eagerly to a clicking of the tongue or slight scratching of the wires which usually preceded the offering of bait. Few white rats had to be discarded, but brown rats were far more difficult; it took 2 or more weeks to train them and not all responded. Their fear was strongly marked and influenced all their actions during training.

A starvation period of 12–24 hours was imposed before the final test which was in some cases composed of two trials: on the first day the animals were fed every 5 minutes for ½ to 1 hour with successive ¼-g. pieces of plain bread paste; on the following day the real poison test was performed. The poison dose, calculated for the body weight, was mostly given in a first 1-g. piece of bread paste and followed at 5-minute intervals by ¼-g. pieces of plain base for as long as the animals would accept. This was the standard method; as will be shown it was not followed in all cases.

These methods give only a rough measure of changes in the attitude of the rats for there are great difficulties in expressing complex behaviour in figures. For example, differences in behaviour of animals tested with 200 and 100 mg. of arsenic per kilo body weight were much more conspicuous than the actual figures of 'hesitation' and 'refusal' suggest. The degree of 'hesitation' was stronger after the higher dose but could not be expressed in figures. Even to record the two points of 'hesitation' and 'refusal' needed a certain amount of experience, particularly the first slight changes of approach, which may be of primary importance in practical operations.

It is possible that the method of conditioning the animals to expect and receive food in short intervals gave a stimulating rhythm to their attitude and prolonged feeding. It was observed several times that when a test was interrupted and the food brought into the cages in a lump, the animals did not eat or show the same interest as when fed by hand.

3. INFLUENCE OF FOOD IN THE STOMACH

With some poisons and low dosages, tests lasted for several hours and there was a danger that animals fed on many successive baits might have shown refusal because of satiation rather than illness. For this reason some animals were tested on the first day with plain bait only, for comparison with results on the day of poisoning.

A special series of tests was also made to determine a rat's capacity for consuming unpoisoned bait at 5-minute intervals. Eight individuals of 115–220 g. body weight were tested and seven of them consumed ¼ g. bread paste every 5 minutes without hesitation for the 7¼ hours of the experiment. The remaining rat reached a state of satiation in 6⅔ hours, as indicated by hesitation and refusal to accept further baits. In a further series of tests nineteen rats, which were given the plain base in excess, ate much more in a limited space of time than the amount of food estimated as necessary in the poison test. These experiments exclude the possibility that the symptoms of hesitation and refusal were merely because of satiation.

Symptoms occurred much earlier in an experiment in which only 3 hours' starvation preceded the poisoning. Two groups of five females were tested, one with 400 mg., the other with 200 mg. arsenic per kilo; a third control group had plain bait only. Lack of hunger made the animals less eager to respond: even the control group had temporary refusal symptoms. In both experimental groups refusal symptoms started earlier than in the corresponding dose groups in previous tests with 24 hours' starvation, and average values were lower. Eight out of the ten animals had their refusal symptoms well in the range of the previous experiment; but two which had had 400 mg. per kilo started as early as 15 minutes, a remarkably short interval.

4. RESULTS WITH ARSENIC

In the first and most important set of eleven tests the sample of arsenic had a fine texture; the range of the size of the particles was roughly 0·003–0·036 mm. diameter, with a greatest frequency of crystals from 0·006–0·009 mm. (Ch. 2). To prevent the danger of day-to-day variation in the results some tests with different doses were done on the same day. Altogether forty-eight white and two wild brown rats were tested for the onset of changes in behaviour and illness, and forty-one of the white rats responded adequately to the requirements of the test. The remaining seven had to be discarded: three had no refusal symptoms at all and four others did not respond because of a fault in the arrangement in the experiment.

(*a*) Hesitation

The first signs of a change in behaviour towards the bait appeared in a wide range of 25–160 minutes; but it appears from the mean figures that the weaker the dose the slower the warning symptoms (Table 1). The speed of action decreases only slightly as the dose falls from 1,000 to 200 mg. per kilo, whereas a sharp gradient is noticeable with doses of 100 mg. per kilo or less.

TABLE 1. *Time of onset of hesitation symptoms (arsenic)*

Dose (mg. per kilo)	*No. of rats*	*Interval before symptoms (min.)* Range	Mean
1,200	4	25–30	28·7
1,000	4	30–60	41·2
800	4	30–60	41·2
600	4	20–70	42·5
400	4	25–75	47·5
200	4	45–65	50·0
100	6	50–70	58·3
75	5	70–120	98·0
50	6	85–160	120·0

The phase of hesitation lasts for a certain time and there are individual differences in its duration. The time intervals between the first sign of hesitation and the first sign of refusal are brought together in Table 2. The individual differences are great, but it appears that after strong doses the action of the poison is more decisive and therefore the period of hesitation shorter. Eleven out of forty-one animals had no hesitation period at all, their warning symptoms appearing at once as refusal. This coincidence of hesitation and refusal seems to be equally distributed over all dose-classes.

TABLE 2. *Duration of hesitation phase (arsenic)*

Dose (mg. per kilo)	*Interval between hesitation and refusal (min.)* *Individual observations*	*Mean*
1,200	0 5 5 10	5·0
1,000	0 5 15 15	8·7
800	0 0 10 10	5·0
600	0 0 5 5	2·5
400	0 0 5 25	7·5
200	5 10 20 25*	15·0
100	0 5 10 20 25 35	15·8
75	0 0 10 10 20	10·0
50	10 10 15 15 50 65	27·5

* In another experiment with 200 mg. per kilo, four rats had hesitation phases of 5, 5, 40, and 15 minutes, with a mean value of 16·2.

(*b*) Refusal

These symptoms were more sharply marked and usually ended the experiment, as from this moment on the feeling of illness became stronger. Symptoms appeared in a range of 25–210 minutes in the total set of experiments. Ranges and mean values at each dose level are given in Table 3.

TABLE 3. *Time of onset of refusal symptoms (arsenic)*

Dose (mg. per kilo)	*No. of rats*	*Time to refusal (min.)* *Range*	*Mean*
1,200	4	25–40	33·7
1,000	4	35–75	50·0
800	4	30–60	46·2
600	4	20–70	45·0
400	4	25–75	55·0
200	4	50–90	65·0
100	6	60–95	74·0
75	5	90–120	108·0
50	6	95–210	147·5

Here again the time before the individual rat refuses further food depends upon the dose initially taken; the smaller the poison dose the longer the time before the animal definitely refuses.

Doses above 200 mg. per kilo gave one refusal period and acute illness followed by death. After doses of 200 and 100 mg. there was refusal for several hours, and in certain cases of slight but prolonged illness bread paste was accepted again. Below 100 mg. one refusal period was followed by further takes of food and refusals up to four times in all (e.g. at 120, 180, 210, 230 mins.). Apparently the feeling of sickness was not strong enough for a clear association to be formed with the food. Those rats treated with low doses (75 and 50 mg. per kilo body weight) accepted the plain bread paste some hours after the poison test and ate an increasing amount during the following days, even in the presence of alternative food.

(*c*) Statistical analysis

The following statistical analysis was carried out by Leslie. From a preliminary survey of these data it appeared that the logarithms of both refusal and hesitation times were linearly related to the logarithm of the doses given. The full analysis was therefore carried out in terms of the logarithms of the individual observations. The following results were obtained for the separate analyses of variance:

	Degrees of freedom	*Hesitation time*			*Refusal time*		
		Mean square	*Variance ratio*	*P*	*Mean square*	*Variance ratio*	*P*
Linear regression . .	1	1·3482	85·2	< 0·001	1·5173	77·7	< 0·001
Deviations from regression line . .	7	0·03246	2·05	0·20–0·05	0·02225	1·14	> 0·20
Error . .	32	0·01583	. .	. .	0·01953	. .	. .

It will be seen that in both cases the regression was highly significant. Comparing the mean square for deviations from the regression line with the mean square for error, it appears that in both cases the straight line was a satisfactory fit to the data, although the variance ratio of 2·05 in the case of hesitation time is rather on the high side. It does not attain, however, the 5% point for 7 and 32 degrees of freedom. The equation relating hesitation time (y) to the dose given (x) was:

$$\log y = 1{\cdot}7354 - 0{\cdot}361\ (\log x - 2{\cdot}3957),$$

and for refusal time (z):

$$\log z = 1{\cdot}8077 - 0{\cdot}383\ (\log x - 2{\cdot}3957):$$

and the geometric mean values calculated from these equations are given in Table 4, together with those actually observed.

The values of the regression coefficients for the two lines were:

$$\text{Hesitation time, } b = 0{\cdot}361 \pm 0{\cdot}056$$
$$\text{Refusal time, } b = 0{\cdot}383 \pm 0{\cdot}046.$$

It is evident that these coefficients are very similar and the difference between them is statistically insignificant. This suggests that the regression lines were running more or less parallel one to the other; and that the differences between the logarithms of hesitation and refusal time were tending to be constant. The logarithm of the ratio (refusal hesitation) time was estimated to be 0·0723 ± 0·0095, and the ratio is thus 1·18. On the average, therefore, for every 100 minutes to the time of hesitation, refusal followed some 18 minutes later.

TABLE 4. *Relationship between geometric mean values for hesitation and refusal times (arsenic)*

Dose (*mg. per kilo*)	*Hesitation time (min.)*		*Refusal time (min.)*	
	Observed	*Calculated*	*Observed*	*Calculated*
50	117·9	96·9	141·9	118·1
75	96·4	83·7	107·5	101·6
100	56·0	75·5	73·5	91·0
200	49·3	58·8	63·3	69·8
400	44·0	45·8	50·2	53·5
600	38·7	39·5	41·0	45·8
800	39·5	35·6	44·6	41·1
1,000	39·9	32·9	47·4	37·7
1,200	28·7	30·8	33·3	35·2

It will be noticed that the arithmetic mean values for warning symptoms given in Tables 1–3 differ slightly from the geometric means in Table 4. The latter were obtained by logarithmic treatment applied throughout in the statistical analysis.

(*d*) Additional observations

(i) *Brown rats.* The two brown rats successfully conditioned and tested gave the following results: ♀ 190 g. treated with successive pieces of poison bait consumed ten ¼-g. pieces of bait containing 250 mg. of fine arsenic. This corresponds to a dose of 1,200 mg. per kilo body weight. Hesitation 40 minutes, refusal 50 minutes. ♂ 170 g. treated as above, consumed nine ¼-g. pieces of poison bait with 225 mg. arsenic (1,320 mg. per kilo body weight). Hesitation 30 minutes, refusal 45 minutes.

(ii) *Lack of warning symptoms.* Symptoms after low doses are late and less strict; a lack of symptoms after the consumption of higher doses seems to be a different phenomenon. Out of thirty-two rats tested with doses of 100 mg. per kilo and over, only two showed no reaction although tested for 3 hours 20 minutes. They received a dose of 400 mg. per kilo and continued to accept pieces of plain food, although signs of illness appeared. Three other rats tested in the same experiment with different doses had clearly pronounced hesitation and refusal reactions. Apparently the non-refusing animals were mentally less able to form an association, and their conditioning to food acceptance may have overwhelmed any other reactions.

(iii) *Phases of illness.* Although special investigations on illness were not undertaken, it is worth mentioning that a fairly regular sequence of phases was observed. In about ½ hour after the consumption of higher doses the rats began to settle in a corner of the cage. They still reacted to luring sounds, were active, and took food. Later on they ceased to react to sounds, only turned their heads and did not leave their corner; they began to search for litter and eat it. Some 50 to 60 minutes from the beginning of the experiment some rats (after higher doses) showed outward signs of illness and lay down. In some cases a period of apparent recovery occurred, e.g. four rats poisoned with 800 and 400 mg. per kilo moved actively 8 hours later and two of them broke out of their cages. They all died in about 40 hours. In all cases a gradual increase of illness followed, sometimes ending with convulsions and a short agony. Diarrhoea was usual even after low doses and a great deal of water was drunk.

(iv) *Time of death.* Time of death was often known only approximately, as many animals died during the night. The interval seemed to be roughly related to the dose consumed, although there were great individual variations (Table 5).

TABLE 5. *Time of death after fine arsenic*

Dose (mg. per kilo)	*No. of rats*	*Time of death (hrs.)*	
		Range	*Mean*
1,200	4	3¼–5	4⅓
1,000	4	5½–15	11
800	4	3¾–38	19⅔
600	4	19¾–31	22½
400	6	4 –81	25½
200	24*	18 –80	36½
100	2	22 –48	47½
50	1	73	

* Including twenty rats from a different experiment.

(v) *A protective habit.* A peculiar habit was often observed with the first onset of symptoms or even before. The rats began to eat the litter (sawdust, peat moss, &c.) or, if none was present, they ate their own droppings or gnawed their wooden cages, but avoided the baits, in spite of hunger. This peculiar habit appeared almost regularly within 25–40 minutes after 100 mg. per kilo or higher doses. Lower doses produced the phenomenon much later (about 100 mins. after 75 mg. per kilo). This habit seemed to show a certain time relation to the symptoms and to be a regular feature in the change of behaviour after arsenic and other poisons. It is not improbable that this is an instinctive reaction against the beginning of illness (Ch. 9). It is very likely that wild rats have stomach and intestinal troubles after the consumption of bad food, and have developed the habit of eating soil for neutralizing pain. In field campaigns with various poisons, stomach contents of wild rats contained earth.

(vi) *Influence of particle size.* Besides the main series, two groups of experiments were designed in the same way to test the influence of texture of the poison on the onset of symptoms. A sample of coarse arsenic was used, with particles ranging in diameter roughly from 0·008 to 0·138 mm.;

most of the crystals were at least 0·03 mm. in diameter. This coarse arsenic was tested simultaneously in two identical experiments using fine arsenic with the greatest frequency of crystal size 0·006–0·009 mm. diameter.

Two groups of five rats were examined, one received an initial dose of 200 mg. per kilo of fine arsenic and the other five rats received the same initial dose of coarse poison (Table 6 (*a*)). This experiment was repeated 5 days later on two other groups of rats with the introduction of a 'time-saving' change of procedure: After the initial poison bait 1 hour's rest was given to all animals and then plain baits were offered at 5-minute intervals. This rendered the experiment much less reliable, as all animals of one of the groups had symptoms of hesitation immediately after resumption of the test (Table 6 (*b*)).

TABLE 6. *Comparative effects of fine and coarse arsenic*

	(*a*)				(*b*)			
			Interval (min.) before				*Interval (min.) before*	
Texture	*Body weight*	*Intake of arsenic (mg.)*	*Hesitation*	*Refusal*	*Body weight*	*Intake of arsenic (mg.)*	*Hesitation*	*Refusal*
Fine	160	32	100	None	180	36	65	70
,,	160	32	70	75	160	32	65	90
,,	170	34	70	75	200	40	65	85
,,	160	32	75	115	150	30	65	90
,,	170	34	65	80	165	32	Discarded	
Coarse	150	30	165	None	190	38	100	105
,,	150	30	135	,,	170	34	105	155
,,	190	38	60	60	150	30	145	None
,,	160	32	155	None	170	34	105	120
,,	160	32	105	105	170	34	Discarded	

In spite of the restricted value of the second experiment some general results are interesting. The symptoms of hesitation were delayed after the consumption of coarse arsenic, their mean value in the first experiment being 124 minutes, in the second 113 minutes, as compared with 76 after the fine texture in the first experiment and their uniformly early appearance in the second. Within the time of the experiments refusal symptoms occurred in only five out of nine animals of the 'coarse' group as compared with eight out of nine in the 'fine' group. In these thirteen animals refusal was mostly earlier in the 'fine' group.

The two textures were of different toxicity: all rats tested with fine arsenic died within 24–80 hours; none of those given coarse arsenic was even seriously ill. The data obtained for the fine powder differ from those in the main test. This may be due partly to individual variation in susceptibility, also to the crude methods of testing, and of expressing behaviour in figures.

In a second test four samples of different particle size were obtained by sieving coarse arsenic. Each sample was tested with a dose of 200 mg. per kilo. Twenty-four rats, 140–270 g. body weight, were tested in all. Only later, during a microscopical examination of the four grades, was it found that they were not uniform and that each contained some fine particles. These were probably produced by the rubbing movements of a brush which was used to speed up the sieving. The results are therefore not reliable in detail, but their general trend is of interest (Table 7):

TABLE 7. *Comparative effects of four grades of arsenic*

Texture group:	*1*	*2*	*3*	*4*
Diameter of particles (μ) .	> 122	71–121	36–70	<35
Range of hesitation symptoms (min.)	55–90	45–90	50–90	30–70
Average (min.) . . .	(78) (5 rats)	69	66	47·5
No symptoms . . .	1 rat	0	0	0
Range of refusal symptoms (min.)	55–110	50–95	50–110	40–105
Average (min.) . . .	. .	81·6	84	75
No symptoms . . .	2 rats	0	0	0

In spite of the faulty technique of sieving the four grades has a different effect. The hesitation symptoms are clearly related to the differences: the finer the texture the earlier the symptoms, the mean for grade 4 (47·5 min.) corresponding well with that in the main test (50 min. for 200 mg. per kilo, Table 1).

The data for refusal times are not so clearly related, though it is significant that no symptoms occurred in three animals, all in the coarsest group. Only five out of twenty-four animals died, all after consumption of grades 3 and 4. It is safe to conclude that coarseness of texture has a delaying effect on the action of arsenic.

5. OTHER RESULTS

(*a*) **Barium carbonate**

A total of twenty-six rats was tested (Table 8). Only four animals were examined according to the standard technique. Four others underwent an experiment in which feeding intervals were kept at 5 minutes for the first 145 minutes, at 10 minutes for the next 75 minutes, and 30 minutes for the last 2 hours. Two rats were given successive poison baits, each gramme containing 0·750 g. poison per kilo. Six animals had a 40-minute interval after the initial poison bait followed by normal successive pieces of plain base. Finally ten animals were tested with an initial poison dose followed by plain bait at 15-minute intervals. All other conditions were kept as in the tests on arsenic.

(i) *General results.* The foremost result is the lack of any symptoms in seven and lack of a refusal attitude in sixteen out of twenty-five successfully tested animals. Sixteen rats showed hesitation to accept further baits: this attitude and refusal were mostly of a passing character. All four females successfully tested had clear warning symptoms. No relationship was found between dosage of poison and the onset of symptoms; those appearing were in the range of 45–205 minutes for hesitation and 45–315 minutes for refusal.

TABLE 8. *Onset of symptoms after barium carbonate*

No. of Rats	*Sex*	*Weight (g.)*	*Method*	*Dose (g. per kilo)*	*Intake of poison (g.)*	*Interval before symptoms (min.)*		*Death (hrs.)*	*Remarks*
						Hesitation	*Refusal*		
1	♀	175	Successive feeding	5·785	1·015	125	130	< 15	Ill in 2 hrs.
1	♀	140		4·842	0·682	75	100	< 15	,,
2	♀	175	Standard	1·500	0·262	Discarded, not responding		< 15	
	♀	155	,,	,,	0·232	105	105		
2	♂	260	,,	,,	0·390	First* 75	175, 315	23	Unrest 75–100 min.
	♂	185	,,	,,	0·277	,, 145	No	< 15	Not ill 6 hrs.
2	♂	140	40-min. interval after poison bait	,,	0·210	,, 205	,,	27–30	
	♂	205		,,	0·300	,, 135	,,	98½	Very ill 66 hrs.
1	♂	250	Standard	0·750	0·187	No	,,	27–30	Not very ill 6 hrs.; very ill 41 hrs.
2	♂	200	40-min. interval after poison bait	,,	0·150	,,	,,	< 17	
	♂	230		,,	0·172	First 105	,,	46½	
1	♀	170	Standard	,,	0·127	125	First 125	Survived	..
5	♂	260	Tests every 15 min.	,,	0·195	,, 45	No	52	..
	♂	270	,,	,,	0·202	,, 45	,,	45	..
	♂	220	,,	,,	0·165	No	45	52	..
	♂	310	,,	,,	0·232	45	60	17	..
	♂	250	,,	,,	0·187	No	60	37	..
5	♂	185	,,	,,	0·138	135	150	110	..
	♂	275	,,	,,	0·206	No	No	37	..
	♂	270	,,	,,	0·202	First 45	No	17½	..
	♂	275	,,	,,	0·206	No	,,	37	..
	♂	210	,,	,,	0·156	,,	,,	16	..
2	♂	190	Standard	0·375	0·071	,,	,,	27	Very ill 26 hrs.
	♂	235	,,	,,	0·088	First 85	,,	Survived	..
2	♂	220	40-min. interval after poison bait	,,	0·082	No	,,	,,	
	♂	220		,,	0·082	First 115	,,	,,	Very ill 44 hrs.

* Other hesitation symptoms followed.

(ii) *Illness and death.* It seems that the delay and indistinct character of the change in behaviour is due to the generally slower onset of illness. The first signs occurred after 2 hours in the case of very high doses, but this was exceptional. In rats treated with equal doses the onset of signs of illness varied between 2 and 48 hours. This is perhaps connected with the conversion of barium carbonate to barium chloride in the stomach, depending upon the presence of hydrochloric acid.

Time of death also varied considerably (from 16 to 110 hours with doses of 750 mg. per kilo). In a larger set of tests on toxicity of barium carbonate over 90% (44 out of 48) of the animals which had taken 750 mg. per kilo or more died within 48 hours. Out of a total of 111 fatal cases in these and other tests only four females died within 10 hours. These figures are in agreement with those of Pemberton (1925) who recorded death in a range from a 'few hours' to 8 or 9 days, but mostly within 3 days. Time of death is not clearly related to size of dose.

(iii) *A surplus feeding test.* Seven female rats were each offered 40 g. bread paste containing 2% barium carbonate. They began to eat at once but soon stopped; some started again later. The amount consumed was checked after 1½ and 4 hours. In only one case was feeding continued after the first 1½ hours. In this experiment warning symptoms started 60–80 minutes after the beginning of the test. One rat ate a sublethal dose, the others were killed.

(iv) *Conclusions.* With barium carbonate it is evident that warning symptoms, if any, occur, on the whole, later than with arsenic. The lack of such symptoms in some rats, their passing character in others, and the absence of any strict relationship between symptoms and size of poison dose are characteristically different from the effects of arsenic and the animals seemed not to associate discomfort with the bait so clearly. Evidently this is because of the delayed onset of illness.

(*b*) Zinc phosphide

There was only one test on groups of four white male rats at three different dose-levels (Table 9). A control group of two animals received plain

TABLE 9. *Onset of symptoms after zinc phosphide (33)*

Body weight (g.)	*Method*	*Dose (mg. per kilo)*	*Intake (mg.)*	*Interval before symptoms (min.)*		*Illness (min.)*	*Death*
				Hesitation	*Refusal*		
285	Standard	80	23	100	110	..	..
260	,,		21	60	65	75	..
220	,,		17	70	105	..	..
200	,,		16	No	No	..	..
270	,,	160	43	45	65	..	..
220	,,		35	45	60	..	..
270	,,		43	70	105	..	..
200	,,		32	35	40	50	1 hr. 15 min.
240	,,	320	76	No	25	25	1 hr. 5 min.
280	,,		89	,,	35	35	1 hr. 40 min.
200	,,		64	,,	20	20	..
210	,,		67	,,	25	20	..

food which they ate eagerly throughout the 120 minutes of the test. All conditions of the test were standard.

The mean times for hesitation and refusal respectively were as follows: *80 mg. per kilo*: 76 and 93 minutes (no symptoms in one animal); *160 mg. per kilo*: 48 and 68 minutes; *320 mg. per kilo*: no hesitation, 26 minutes for refusal. The onset of severe illness is so quick (20 mins.) after high doses that it causes a sharp interruption of feeding without preliminary symptoms. There is a much sharper rise of effects with the increase of dosage than with arsenic. Death is also quick, three of the rats died within 120 minutes; the exact time was not recorded for the others, but all died within 24 hours.

(*c*) Red squill

Only two small tests were done, one with red squill powder, the other with red squill extract. The powder was a stablactivated (S.A.L.A.M.) sample offered in bread paste. All other conditions were as in the tests on arsenic, except that the initial poison bait was followed by an interval of 25 minutes before the usual 5-minute offerings of plain bait and there was another 75-minute interval after 2 hours. Three females and one male were observed for 4½ hours. The extract was given to four females, in three 1-g. pills of bread paste, each containing 100 mg. of extract. This extract had a toxicity of 300 mg. per kilo. After the three initial poison baits the usual standard technique was applied.

These results (Table 10) are too small to yield general conclusions but seem to indicate that red squill powder, judging by refusal times, acts more slowly than some mineral poisons; though, admittedly, some earlier symptoms may have been overlooked. The male was affected less than the females, which is in conformity with previous observations.

TABLE 10. *Onset of symptoms after red squill powder and extract*

Sex	*Weight (g.)*	*Method*	*Dose (mg. per kilo)*	*Intake of poison (mg.)*	*Interval before symptoms (min.)*		*Death (hrs.)*	*Remarks*
					Hesitation	*Refusal*		
♀	170	Interval of 25 min. after initial poison bait	250	42	95	210	8–10	Convulsions 253 min.
♀	150		250	37	90	110		,, 270 ,,
♀	135		250	34	95	115		,, 205 ,,
♂	170		450	76	125	248•	Survived	Slight signs 235 min.
♀	150	Three poison baits, then standard treatment	1,980	*c.* 300	Not recorded	105	< 20	Slight illness appeared during the 105 min. of the experiment
♀	170		1,740	,,		70		
♀	150		1,980	,,		25		
♀	200		1,500	,,		55		

• Temporary.

The toxic dose in the extract was much higher, nevertheless only one animal showed refusal symptoms as early as 25 minutes, the average was 64 minutes for four animals. Illness came early in both cases with violent convulsions. The females died after 8 hours. The extract acted more quickly because the dose was higher.

(*d*) Alpha-naphthylthiourea

Twelve medium-sized white rats, six males and six females, were tested after 12 hours' starvation. A uniform amount of 3 or 20 mg. of alpha-naphthylthiourea in bread paste was given to two groups of rats, each composed of three males and three females. The dose per kilo body weight therefore varied according to the size of the rat. The standard method was employed for the first 100 minutes, and after an interval of 110 minutes, testing was done at 15-minute intervals. The animals were tested for 5 hours altogether; with one more offering of plain base at 6¼ hours.

There was no significant difference in the onset of symptoms between animals which ate the high and the low doses (Table 11). The earliest symptoms recorded were at 25 minutes for hesitation and 40 minutes for refusal, but most animals took longer, and average times for hesitation in both groups were about 65 minutes. Refusal symptoms had a wide range, but for eight out of twelve animals were about 100 minutes or over.

Table 11. *The onset of symptoms in twelve white rats tested with alpha-naphthylthiourea*

Sex	*Weight (g.)*	*Method*	*Dose (mg. per kilo)*	*Intake of poison (mg.)*	*Interval before symptoms (min.)*		*Illness* (min.)*	*Death. (hrs.)*
					Hesitation	*Refusal*		
♂	200	Standard for 100 min.	15	3	50	60	60	25
♂	230		13	,,	55	80	..	29
♂	160		18	,,	60	100–210	..	< 48
♀	140		21	,,	No	40	60	,,
♀	150		19·8	,,	70	240	..	*c.* 52
♀	220		13·5	,,	90	100	95	< 23
♂	170		116	20	80	210	..	,,
♂	195		102	,,	25	40	..	,,
♂	150		132	,,	70	100	..	,,
♀	230		87	,,	60	95	60	,,
♀	140		142	,,	70	225	..	,,
♀	200		100	,,	75	100	.	,,

* Only slight illness at the times observed.

A striking feature was a repeated take after previous refusal. Only four rats refused permanently, the others accepted bait again 4–6 hours after the start. Several animals took a piece of the plain food, chewed a little, then slowed down in eating and finally dropped the bait.

Symptoms of discomfort and illness were first shown by three animals eating litter at 25, 45, and 55 minutes. Three animals showed slight illness by lying down flat at 60 minutes and another rat lay down at 95 minutes. Most of the animals became really ill after 2–3 hours; but illness came on slowly without violent signs. All animals of the 20-mg. group and one of the 3-mg. group died within 23 hours; two died between 29 and 48 hours and the other three in 25, 29, and about 52 hours.

In addition, a feeding test may be mentioned in which each of five recently trapped brown rats (♀♀ 80, 190, 260, 280 g., ♂ 350 g. body weight) was given a 2-g. bait of wet rusk and 40 mg. alpha-naphthylthiourea after 24 hours' starvation. The bait was consumed in the first 25 minutes, and 10 g. plain base was given 40 minutes after the experiment began. One rat did not touch this plain bait, the others ate varying amounts within the next half-hour. All feeding stopped in 2 hours or less from the start, although there were no apparent signs of illness. All were ill after 6 hours and died within 20 hours.

(*e*) Sodium silicofluoride

A brown male and a white female were fed with successive small pieces of poison bait each containing 25 mg. of the poison in bread paste. The brown rat ate 75 mg. poison and symptoms appeared in 15 minutes as refusal. The white rat ate 100 mg. of the poison, and first hesitated after 15 minutes and finally refused after 20 minutes. Death occurred within 6 hours in the white and within 20 hours in the brown rat.

6. DISCUSSION

The most important result of the experiments consists in establishing a definite connexion between the action of poison bait and the immediate behaviour of the tested animals. For some time after having consumed a poison bait the tested rats were still eager to accept further bits of unpoisoned bait at 5-minute intervals, until apparently the poison began to act. Under the influence of poison action the animals' attitude towards further acceptance of bait changed. Mostly two distinct phases could be recognized, first a 'hesitation' period, developing later into a stricter 'refusal' phase (Table 12). In some cases the first symptoms were sudden refusal; in a few cases the rats did not refuse in spite of illness.

The 'hesitation' phase appeared first as a slackening in the eagerness of further acceptance. The rats sniffed carefully at the bits of food, accepted more and more reluctantly, ate slowly, and sometimes dropped the bait. No outward signs of illness had yet appeared. This phase lasted for some time with the action of the poison developing more or less quickly according to the kind and dose until the hesitating attitude turned into refusal.

The 'refusal' phase was generally marked by a sharp change in behaviour. No outward signs of illness were yet visible with some poisons, e.g. arsenic; but discomfort at least was probably felt. The rats turned their heads away when bait was brought near them, some pushed it aside with their forepaws or grasped it fiercely, dropped it, or buried it in the litter. Sometimes they attacked the bait stick. In other cases, e.g. with barium carbonate or low doses of arsenic, refusal was not permanent and was followed by repeated acceptance.

When the poison begins to act in the mouth, in the stomach, and through blood circulation, discomfort and increasing illness are felt. This is a purely physiological process growing in strength with time. It is reflected closely in behaviour; in other words a psychological process is called into action. The two processes, one initiated by the other, act parallel for some time; slight irritation causes hesitation, stronger discomfort causes refusal.

TABLE 12. *Time of onset of symptoms after the main poisons*

Poison	*Doses (mg. per kilo)*	*Interval before symptoms (min.)*		*Earliest*	
		Hesitation	*Refusal*	*Illness*	*Death*
Fine arsenic	50–1,200	25–160	15*–210	50 min.	3½ hrs.
Coarse arsenic	200	60–165	From 60–	Not visible	Most survived
Barium carbonate†	365–5,700	45–205 Occurred only in some animals	45–315	2–3 hrs.	< 15 hrs.
Zinc phosphide	80–320	(20)‡–100	20–110	20 min.	65 min.
Red squill powder	250–450	90–125	110–248	3–4 hrs.	8–10 hrs.
Red squill extract	300	Not clear	25–105	105 min.	< 8 hrs.
Alpha-naphthylthiourea	13–142	25–80	40–240	60 min.	< 23 hrs.
Sodium silicofluoride	*c.* 600	15	15–20	..	6 hrs.

* See § 3. † Action irregular. ‡ Hesitation coincided with refusal.

Judging by its outward signs, an 'association' is formed between discomfort or illness and the bait just consumed. (This is confirmed by the subsequent behaviour of survivors—Appendix 1.) Only when the animals first feel ill is it clear that the association is specific, i.e. directed against the bait just consumed. Increasing illness leads to a general aversion for food (sick animals ate little or nothing); but it would be erroneous to conclude that there was only this general avoidance of food. As seen in survivors, the specific aversion with which the tested animal probably started is revived later when the general aversion has passed away.

7. SUMMARY

1. The onset of the effects of poison and resulting changes in behaviour were studied in white and a few brown rats. Animals were first conditioned over a period of days to take baits given by hand. Then an initial poison bait was offered followed by ¼-g. pieces of plain bait base at 5-minute intervals for as long as the animals would accept it. This standard method was altered in some cases.

2. Preliminary tests without poison showed that rats starved for 24 hours

can feed in this way for more than 6 hours without reaching a state of satiation.

3. Under the influence of poison action there was a visible change of behaviour towards further bait acceptance: very often a phase of hesitation appeared first, followed by more or less strict refusal of further bait. These reactions were said to be evoked by 'warning symptoms'.

4. The speed of onset and the strength of these symptoms varied according to the poison, and in the case of arsenic and zinc phosphide to the dose. Barium carbonate did not always create clear symptoms, they are not related to the dose and refusal was often of a passing character.

5. Other factors influencing the appearance of symptoms were the texture of the arsenic, and probably the state of satiation before the test. There were also differences between individual rats.

6. Lack of symptoms was observed several times. Small doses of fine or even big doses of coarse arsenic sometimes failed to produce reactions. Apparently the feeling of illness was not strong enough to create an aversion to the bait. However, even illness from arsenic poisoning failed to produce a change of behaviour in two animals—which still continued feeding. These animals were evidently less able to form a strong enough association to overcome the acquired habit of rhythmical food acceptance.

7. With the advance of illness, depending upon poison and dose used, a general aversion to food overwhelms the specific refusal of the bait. Survivors drop the general aversion after recovery, whereas the specific avoidance of the experienced bait very often remains (or reappears) in varying strength (Appendix 1).

8. The main results are given in Table 12 as ranges of time in which symptoms appeared after the consumption of various poisons. It should be emphasized that the times are only approximate and apply to laboratory conditions.

9. The results for arsenic were statistically tested. A constant relationship was found between the times of hesitation and refusal: on the average, for every 100 minutes to the time of hesitation, refusal followed some 18 minutes later.

APPENDIX 1

THE PERSISTENCE OF BAIT-SHYNESS

RATS have frequently been observed to avoid poison baits, especially in successive campaigns. In initial treatments such failures are mainly due to faulty methods, that is to external factors; but in successive treatments the rats' previous experience of poison baits constitutes an additional, internal factor. In order to find out the circumstances under which poison bait was avoided a series of experiments was made in the laboratory on a total of 180 white rats (pure bred Wistar albino) and a few brown wild rats. The conclusions are summarized below.

1. White and a few wild brown rats were subjected in the laboratory to initial and successive poison tests with changes of poison and food medium (base). Poisons included arsenic, barium carbonate, and red squill powder.
2. An initial poison bait was accepted and consumed by a majority of rats which had had no previous experience of poison.
3. In most experiments only a small number of animals refused such initial baits completely or partly.
4. Survivors of an initial poison bait showed a more or less definite refusal or shyness towards further baits or even towards the base alone. A general rise in caution and probably a higher state of sensual alertness develops as a result of poison experience. This is to be distinguished from mere avoidance of food through illness.
5. The majority of animals in our experiments followed these four 'rules' in their approach to successive baits:
    - (*a*) An identical poison bait was refused.
    - (*b*) A new poison in a base harmfully experienced was refused.
    - (*c*) An experienced poison in a new base was mostly accepted.[1]
    - (*d*) A new poison in a new base was accepted.
6. These results show that although the poison creates illness or discomfort, memory of it persists through the properties of the base; hence the conception of 'base-shyness'.
7. For most rats a harmful experience is needed if they are to recognize and refuse a later poison bait; initial avoidance occurs only in a small percentage of animals, provided, of course, that the bait itself is not repellent or avoided for other reasons.
8. Base-shyness develops quickly or slowly following the action of the poison; it may appear in a range of ½ hour to several days.
9. Various factors influence the strength, development, and direction of shyness. There are indications that some poisons, e.g. barium carbonate and some samples of red squill, create less strict avoidance of further baits than, for example, arsenic. This last poison's effect was found to depend on its texture. The dose influences the speed of development and the strength of discomfort or illness and thereby the strength and duration of association

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[1] Red squill not extensively tested on this point.

and memory. The nature of the base, its structure, taste, and flavour, contribute to differences in the strength and direction of shyness; sweetening and flavouring facilitate associations.

10. Successive associations with poison bait influence each other; consumption of weak identical baits reinforce memory and reaction; with a succession of different baits memory of the last one may overwhelm that of a previous one.
11. The memory of red squill bait may last as long as 374 days in individuals; incidental observations show that baits with barium carbonate and arsenic were remembered at least for 2 months.
12. Hunger acts against bait refusal when other food is not available. Tentative consumption may start and, when a plain base is offered, shyness may be overcome. On some such occasions the animals continued to eat subnormal amounts, showing that shyness was only partly suppressed.
13. The general rise in alertness is markedly shown in the discrimination of poison bait by experienced rats. In some cases the sense of smell undoubtedly allows the rats to identify a bait without testing; e.g. starchy baits with arsenic were discriminated in this way by brown rats, probably because of the arsene gas given off.
14. Discrimination by taking small quantities of a suspected food is very common. When plain food is approached in this way, tentative consumption goes on as no symptoms arise to reinforce shyness. When a known poison is added to the base the rats have experienced, the tentative feeding, initiated by hunger drive and the prebaiting effect of the plain base, generally stops in a short time; probably taste-memory is revived more strictly, and slight symptoms of discomfort may start. In this way the poison bait is very often rejected and the plain base is consumed. The latter result may lead to the wrong assumption, that base shyness is lacking.
15. Sample take may thus lead to discovery of the harmless or noxious nature of a bait. Sometimes it reinforces previous associations, on other occasions it weakens them. Sample take is a most important factor in rat's behaviour towards poison bait.
16. A small number of animals was observed to differ from the general behaviour of the majority. These rats displayed 'individual behaviour' by refusing even the initial poison baits or by showing a much higher or lower standard of caution towards successive baits. Some stubbornly refused any poison bait, some displayed special abilities in sampling. Great individual variations were found in the strength of memory and susceptibility to poison.
17. The basic mental equipment of white and wild brown rats is probably similar. Yet field observations and a study of relevant literature brings us to the conclusion that the acuity of senses and the range of experience is higher in wild brown rats. Their state of alertness is stimulated strongly by fear and wildness.

APPENDIX 2

INTAKE ACCORDING TO CONCENTRATION OF POISON

After certain poisons symptoms of illness tend to appear earlier with increasing concentration in the bait. As these symptoms usually end feeding, their delayed onset after low concentrations allows more time for feeding. Consequently one would expect the intake of bait to be related to its concentration of poison, a point of some interest in control operations.

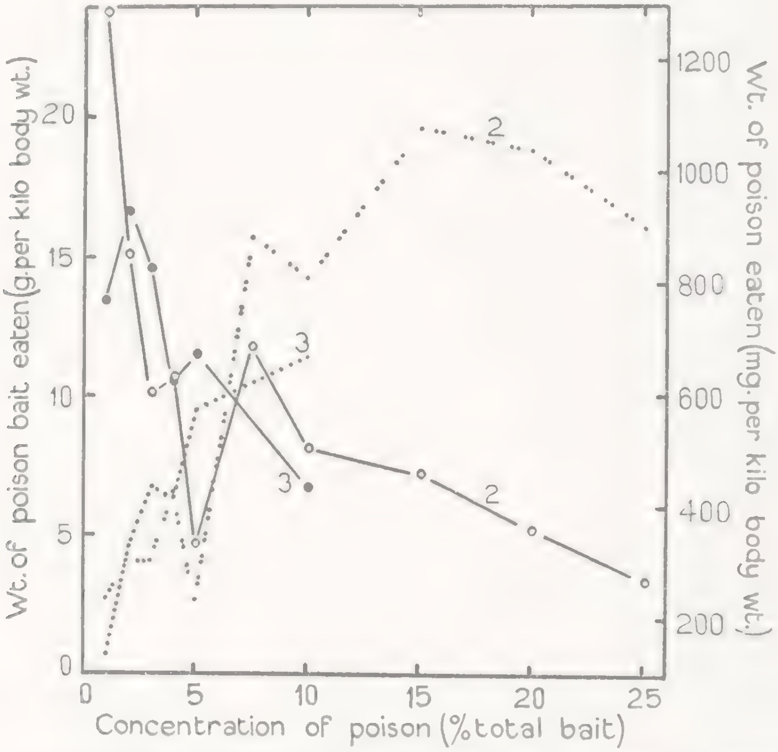


Fig. 1. Relationship between intake and concentration of arsenic (experiments 2 and 3, Table 13). Solid lines: poison bait; dotted lines: poison.

White and brown rats were used in experiments to inquire into this question. The rats were offered a surplus of poison bait and residues were weighed after 3–4 hours when obvious illness made further intake improbable. Each animal was kept in a separate cage with adequate water supply and for some days before the test was fed on the plain base. Twenty to twenty-four hours' starvation was imposed before poisoning. All animals were of medium size (150–270 g.), with the exception of a few brown ones, which were 70–100 g. in weight. Despite great variations within and between the tests the general trends are sufficiently clear. On the whole, intake of bait declines with increasing concentration; but, in terms of arsenic itself (Table 13 (*a*)), intake rises with the concentration. Two examples are plotted in Fig. 1. Zinc phosphide was given to six groups of three male white

TABLE 13. *Mean intake in g. per kilo body weight of poison bait (PB) and poison (P) according to concentration*

(a) Arsenic

Expt. No.	Animals	Base		Concentration of poison (%)									
				1	2	3	4	5	7·5	10	15	20	25
1	White ♀♀	Flour	No. of animals:	..	5	..	..	..	..	3	..	..	..
			PB	..	10·33	..	..	..	..	4·45	..	..	..
			P	..	0·207	..	..	..	..	0·445	..	..	..
2	Brown ♂♂+♀♀	Kibbled wheat	No. of animals:	1	1	1	1	1	1	1	1	1	1
			PB	23·8	15·1	10·1	10·7	4·7	11·8	8·1	7·2	5·2	3·6
			P	0·238	0·302	0·303	0·428	0·235	0·885	0·810	1·080	1·040	0·900
3	White ♂♂+♀♀	Bread paste	No. of animals:	4	4	4	4	4		4			
			PB	13·5	16·6	14·6	10·5	11·5	..	6·7	..	..	..
			P	0·135	0·332	0·438	0·420	0·575	..	0·670		..	..
4	White ♀♀	Flour	No. of animals:	..	* 15	..	..	16	..	16	..	..	
			PB	..	c. 25*	..	..	41·3	..	16·5	..	..	..
			P	..	0·500*	..	..	2·065	..	1·650			..

(b) Zinc phosphide

Expt. No.	Animals	Base		1	2	3	4	5	7·5	10	15	20	25
5	White ♀♀	Flour	No. of animals:	3	3	3	3	3	..	3			..
			PB	24·8	24·7	21·3	19·6	14·0	..	13·1	..	..	..
			P	0·248	0·494	0·639	0·784	0·700	..	1·310	..		..

* Approximate figure, as some body weights were not recorded.

rats at six different concentrations in plain wholemeal flour (Table 13 (*b*)). Again, with the rise in concentration, intake of the entire bait decreases whereas intake of the poison itself continues to increase.

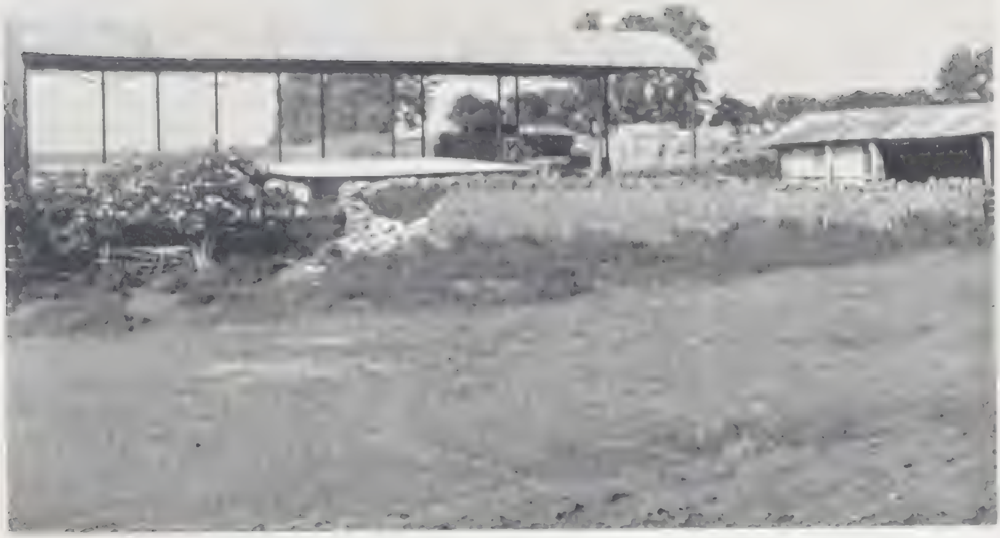
These experiments show that, on the whole, the higher the dose of poison the less bait was eaten, but that the intake of pure poison was greater. However, it is to be expected that above a certain concentration the intake of poison becomes progressively less as the bait becomes unpalatable. The present tests were not sufficiently extensive to show the optimum concentration; but with kibbled wheat there is a suggestion that intake of arsenic levels off at 15–20%, and may decrease above this.

McDougall (1944) obtained similar results with captive *R. conatus* given thallium sulphate in a meal bait.

REFERENCES

McDougall, W. A. (1944). 'An investigation of the rat pest problem in Queensland canefields: 3. Laboratory experiments on food intake and toxicity.' Qld J. Agric. Sci. 1, No. 3: 1–32.

Pemberton, C. E. (1925). 'The field rat in Hawaii and its control.' Bull. Hawaii. Sug. Ass. Ent. Ser. No. 17: 1–46.



(*a*) General view of rat infested farm premises with Dutch barn, Worcestershire

(*b*) Rickyard, Berkshire

PLATE 5

(*a*) Rural rubbish dump, Oxfordshire

(*b*) Field bank infestation, Lincolnshire

PLATE 6

Baiting sewer rats from street level, Oxford

PLATE 7

(*a*) Transit shed, Haifa

(*b*) Cellar, Khartoum

PLATE 8

9

STOMACH ANALYSIS OF BROWN RATS POISONED IN THE FIELD

By J. RZÓSKA

1. INTRODUCTION

EVERY rat campaign reaches its culminating point with the exposure of poison bait. Then the animals themselves have to act, and their response to poison bait determines the result of the campaign. The rats have to find the bait, to approach it confidently and consume adequate amounts. Each poison allows feeding to go on for a limited time only; zinc phosphide and arsenic in particular quickly create symptoms of discomfort which stop or slow down feeding. Obviously then, the most decisive phase of the campaign is that short space of time after consumption begins. Analysis of stomach contents supplies some information about what happens, and some 1,300 rats were dissected for this purpose.

The weight of the full stomach of seventeen adult brown rats of 270–490 g. body weight ranged from 20 to 52 g., or between 6 and 12%, with an average of 9% of the body weight. (The daily consumption of a medium-sized brown rat (200–250 g.) is about 25 g. dry wheat (Ch. 6) which has a volume of 20 c.c. measured by water displacement.) The empty stomach of fully grown rats varies from 2 to about 5 g., the average for seven rats of medium size was about 3·2 g., that of a 50-g. male weighed 0·3 g. empty and 2·6 g. full.

According to Jaffé (1931) food begins to leave the white rat's stomach about ¼ to ½ hour after intake. A meal has left the stomach completely after about 7 hours. The residue of a grain meal begins to appear in the droppings of rats and mice after about 3–5 hours, and excretions continue for 3–6 days. In some of our own white rats the stomachs were still full 4 hours after a meal of wheat, began to empty after 6 hours, became practically empty after 12 hours, and the rest of the gut emptied after about 72 hours. When poison bait has been ingested the rats stop feeding in a short time and many die within 1 or a few hours. Other poisons act very slowly and rats may revert to feeding on plain food. Thus McDougall (1944) found that between the ingestion of a dose of thallium sulphate and the onset of gross symptoms rats may feed more or less in a normal manner. Quick acting poisons will mostly be found near the entrance from the oesophagus, since the poison has no time to change considerably or to move on.

2. METHODS

Each animal was sexed and weighed, the stomach was cut out, weighed as a whole, and opened. Notes were made on the state of fullness and food constituents as far as discernible. The poison bait was scratched out with a spatula, transferred to a watch glass, and weighed. In many cases the poison bait could be separated easily and with negligible loss, especially in the case of zinc phosphide in moist rusk. Sometimes, however, the contents were watery or mixed with the food or too minute for measurement. Watery poison contents were often dried to an approximately normal consistency for that particular bait and then weighed. Some animals ate enough poison bait to be killed but not enough for it to be measured.

The most satisfactory results were obtained with zinc phosphide in rusk. Such baits killed the animal within a few hours and no major changes could take place after ingestion. The bait was mostly found compact and of the same consistency as the fresh bait. It usually formed a dark coloured 'cap' lying on the remaining stomach contents and occupying more or less of the cardiac part, extending from there towards the pyloric end of the stomach. Baits with sugar-meal did not offer such good conditions for examination, as they were often watery, but here again the impression was gained that the poison bait could not have left the stomach into the intestines because of the rapidity of action. Such was not the case with red squill powder or extract. This poison may take hours to kill and rats are observed rolling in convulsions many hours after the exposure of poison bait. During this time the action of the stomach may not be interrupted: sometimes the intestines were inflamed and filled with reddish-brown slime, apparently from the poison bait. Therefore not much importance can be attached to examination of corpses resulting from red squill. (It is remarkable that in tests on white rats there was no indication of big losses of this poison bait into the intestines.) With arsenic the samples are too small since few corpses are found.

To test the accuracy of the method and in particular to find out to what degree the amount of bait found in the stomach corresponds to the amount originally consumed, a number of feeding tests was undertaken. White rats were given a measured surplus of three different poisons in moist rusk and after the death of the animals the amounts found in the stomachs were compared with the amounts which had disappeared from the feeding trays. Throughout the whole of the experiments water supply was adequate and spillage from the food trays was negligible.

Table 1 shows that the weight of the stomach contents corresponded fairly well with the amounts taken from the trays. It therefore seems probable that, at least with zinc phosphide in moist rusk, the amount of poison bait found in an animal killed in the field corresponds roughly with intake.

Laboratory tests with sugar-meal showed that because moisture had been taken up the amounts recovered from the stomach were much greater than those taken from the tray. Field evidence about this poison bait will therefore not be dealt with.

TABLE 1. *Amount of bait (1 : 1 rusk) eaten and amount recovered from the stomachs of white rats*

Poison	*No. of rats*	*Mean intake (g.)*	*Mean stomach contents (g.)*	*Mean difference and S.E.*
5% zinc phosphide .	14	5·51	5·02	−0·479±0·196
7·5–10% arsenic .	10	5·24	5·05	−0·190±0·302
10% squill powder .	13	5·27	4·83	−0·438±0·289

3. RESULTS

Results are available from twelve campaigns conducted with moist rusk and 5% zinc phosphide (2% in sample No. 10) in the country and in the London sewers. The amount of prebaiting varied (Table 9). Eleven of these samples, comprising 509 bodies, were examined by the writer, and a further sample was examined by the Infestation Branch of the M.O.F.

(*a*) Relation to food in the stomach

In most cases the food could be identified and the diet reflected local conditions quite well. Animals under 50 g. very often had milk in their stomachs, showing that some can be poisoned before being fully weaned. Table 2 gives qualitative evidence that large amounts of poison bait were

TABLE 2. *Relation between the amount of food and poison bait in the stomachs of wild rats*

Sample No.	*Habitat*	*Proportion of rats with unmeasurable amounts of poison bait*	*Stomach contents*	
			Much poison bait	*Little or no poison bait*
1	Straw-rick, banks	10/17	Little food	5/10 plenty of food
2	Wheat-ricks	13/33	,,	9/13 ,,
3	Wheat-ricks	27/47	,,	Mostly with food
4	Hedge, ditch	8/17	,,	Presence of food
5	Rubbish dump	7/21	No records	..
6	Barn with oats	12/36	No food	10/12 with food
7	Farm	23/110	Digested food only	Presence of fresh food
8	Rubbish dump	3/24	No food	Food present
9	Farm	1/12	Less than half-full of food or with none	One animal, killed by force
10	Wheat-ricks	0/14	Little or no food	..
11	Sewers	40/178	No food	Some food present

mostly correlated with little or no food in the stomach. When little or no poison bait occurred there was often a considerable amount of food. Between these extremes there were animals with varying amounts of food and poison bait. Samples 2 and 8 showed this relationship in a marked way (Table 3).

TABLE 3. *Amount of food and poison bait in stomach contents of two samples of rats*

Amount of food	*Wt. class of poison bait (g.) and frequency*																		
	*0**	*–1*	*–2*	*–3*	*–4*	*–5*	*–6*	*–7*	*–8*	*–9*	*–10*	*–11*	*–12*	*–13*	*–14*	*–15*	*–16*	*–17*	*–18*
Sample No. 2 Much	9	4	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
Some	4	5	2	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
Little or none	. .	4	1	2	1	1	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
Sample No. 8 Much	1	1	. .	1	1	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
Some	2	2	. .	2	2	1	. .	1	. .	. .	. .	. .	. .	2	. .	. .	. .	. .	. .
Little or none	. .	. .	. .	. .	1	1	. .	. .	2	. .	. .	1	1	. .	. .	. .	1	. .	1

* Or not measurable.

Since the amount of normal food in the stomach evidently cuts down the intake of poison bait it is clearly important, by prebaiting or interception or both, to ensure that wild rat populations feed on the operator's bait before finding anything else. The extent to which this task was achieved will be discussed later on; but even in the best cases of conditioning some animals showed individual behaviour in feeding.

(*b*) Relation to body weight

Individual data were grouped into classes of body weight and corresponding classes of bait consumption, but only three samples were large enough for analysis. With two minor exceptions the absolute intake of poison bait increases with each weight class (Table 4), and as shown by Table 5 the intake within each sample was fairly constant in terms of g. per kilo body weight.

An analysis of variance was carried out by Leslie as follows:

Sample No. 7

	Sum of squares	*d.f.*	*Mean square*
Between groups	33·0497	5	6·6099
Within groups	627·8009	81	7·7506
Total	660·8506	86	. .

It is clear from this analysis that there is no evidence in this series of results of any significant differences in intake per kilo body weight between the body weight classes.

Sample No. 11

	Sum of squares	*d.f.*	*Mean variance*	*Variance ratio*
Between groups	35·5068	5	7·1014	1·91
Within groups	489·4281	132	3·7077	
Total	524·9349	137		

The ratio between the two mean variances is 1·91, which does not attain the 5% point for 5 and 132 degrees of freedom. So far as this evidence goes we cannot say that there was any significant difference between the weight groups.

Sample No. 12

	Sum of squares	*d.f.*	*Mean square*	*Variance ratio*
Between groups	43·5669	4	10·8917	3·53
Within groups	287·1780	93	3·0879	
Total	330·7449	97	.	..

The variance ratio is 3·53 and for 4 and 93 degrees of freedom *P* is approximately 0·01. Thus in this case the weight classes do appear to differ in their mean intake per kilo body weight. It can be seen from the table that this result is largely due to the relatively very high intake recorded in the animals weighing between 151 and 200 g.

We may conclude that, with the possible exception of two of the five weight classes in sample 12, successive classes consumed a higher absolute amount of poison bait but a more or less similar amount relative to body weight. This suggests that within each colony there was a fairly uniform attitude of the majority of animals towards the poison bait, and that intake

TABLE 4. *Mean consumption of poison bait per individual according to body weight*

Body wt. class (g.)	*Sample No. 7*		*Sample No. 11*		*Sample No. 12 (M.O.F.)*	
	No. of bodies	*Av. consumption (g.)*	*No. of bodies*	*Av. consumption (g.)*	*No. of bodies*	*Av. consumption (g.)*
−100	22	2·04	9	4·75	8	5·03
101−	12	1·38				
151−	13	4·25	16	8·97	24	8·77
201−	13	5·17	41	11·11	29	9·75
301−	22	8·95	57	12·73	32	11·35
401−	5	12·38	15	17·16	5	10·30

TABLE 5. *No. of rats eating various amounts of poison bait per kilo body weight*

	Sample No. 7							*Sample No. 11*							*Sample No. 12 (M.O.F.)*					
Poison bait consumed (g. per kilo body wt.)	*No. of rats in each weight group*							*No. of rats in each weight group*							*No. of rats in each weight group*					
Body wt. (g.):	*−100*	*101–*	*151–*	*201–*	*301–*	*401–*	*Total*	*−100*	*101–*	*151–*	*201–*	*301–*	*401–*	*Total*	*−150*	*151–*	*201–*	*301–*	*401–*	*Total*
< 5	..	2	1	2	1	..	6	..	..	..	..	..	..	..	..	..	..	..	..	..
5–	2	3	..	1	3	..	9	..	..	..	2	6	..	8	1	..	3	2	1	7
10–	2	2	2	2	4	..	12	..	..	..	..	..	..	..	..	..	..	..	..	..
15–	5	1	2	..	4	1	13	1	..	3	6	10	5	25	2	2	2	6	1	13
20–	5	..	2	5	1	1	14	..	..	..	..	..	..	..	..	..	..	..	..	..
25–	2	2	3	..	2	2	11	1	2	3	10	10	..	26	1	3	11	8	3	26
30–	2	1	..	1	1	..	5	..	..	..	..	..	..	..	..	..	..	..	..	..
35–	1	..	2	1	2	..	6	..	1	2	9	18	3	33	1	7	4	9	..	21
40–	1	..	1	1	..	..	3	..	..	..	..	..	..	..	..	..	..	..	..	..
45–	2	1	..	..	1	1	5	..	1	4	2	7	6	20	..	4	4	4	..	12
50–	..	..	..	..	1	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..
55–	..	..	..	..	1	..	1	..	1	1	4	2	1	9	3	..	2	1	..	6
60–	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
65–	..	..	..	..	1	..	1	..	..	2	4	4	..	10	..	6	2	1	..	9
75	..	..	..	..	..	..	..	..	1	..	1	..	..	2	..	1	1	1	..	3
85	..	..	..	..	..	..	..	..	..	1	3	..	..	4	..	1	..	..	..	1
95	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
105	..	..	..	..	..	..	..	..	..	1	..	..	..	1	..	..	..	..	..	..
Total	22	12	13	13	22	5	87	2	6	17	41	57	15	138	8	24	29	32	5	98
Mean (g.)	24·3	17·1	23·7	20·2	25·2	28·5	23·07	25·0	48·3	48·8	43·2	36·0	41·3	40·22	37·5	50·0	37·9	35·9	24·0	39·49

was partly limited by some uniformly acting factors. One of these is certainly the onset of symptoms, which is most likely to be uniform and finally bars any further consumption. Another is probably the eagerness of feeding.

In some of the smaller samples the population was probably less uniform and may have been disturbed by other factors. Such possible factors are discussed below but the experiments of McDougall (1944) on *R. conatus* may be noted here. Animals were given baits of thallium sulphate at intervals of several days and it appears from his tables 21–23 that initial feedings showed a similarity of bait consumption per unit body weight within the various dose classes. Further offers of poison, however, led to wide differences of individual acceptance among the survivors.

(*c*) Differences between populations

(i) *Mean detectable intake.* In Table 6 the average consumption of poison bait in each of our 12 samples of rats is expressed in grammes per kilo body weight, with standard error and also the number of rats in which poison bait could be measured.

Leslie commented: Two of these samples, Nos. 7 and 11, are fairly large. There can be little question that these mean intakes are significantly different. Many of the other samples are small, however, and the degree of variation of the individual entries is on the high side. The analysis of variance for the remaining nine groups was:

	Total sum of squares	*d.f.*	*Mean square*
Between groups	13663·650	8	1707·956
Within groups	27177·984	131	207·466
Total	40841·634	139	

The ratio between the two mean variances is 8·23, and for 8 and 131 degrees of freedom, $P < 0{\cdot}001$, which is highly significant. There is no doubt that even in the small samples, the differences between the mean consumptions per kilo body weight are significantly marked.

Table 6 proves that the different colonies of rats differed in the intensity of time of feeding on a poison bait of the same kind. The eleven samples are arranged in a progressive sequence according to the increase in consumption of zinc phosphide bait, which, in the samples from the London sewers, is almost 10 times as high as in that from the rural environment heading the list. These big differences can be due only to a difference in the eagerness and speed of feeding in the initial phase of contact with the poison bait before the onset of illness. It may be safely assumed that no more than 25 minutes may be allowed for this phase.

(ii) *Unmeasurable intakes.* Table 6 also shows the number of animals in each sample in which the poison bait could be measured. In the others the amounts were in most cases, unmeasurable; but occasionally small amounts of poison bait were mixed with a varying amount of food. Most of these rats probably stopped feeding after a very short time, for various reasons, e.g. feeding habits, interference, individual behaviour. These rats of course form a part of the treated population, and must be taken into account, but our calculation of the mean intake relates only to that part of the population in which intake could be measured.

TABLE 6. *The mean consumption of poison bait in 12 campaigns (g. per kilo body weight)*

(Samples 1–11 are numbered according to increasing mean consumption)

Sample No.	*Proportion of stomach contents measured*		*Mean consumption of poison bait (g. per kilo body wt.)*
	Nos.	%	
1	7/17	41·1	4·26 ± 2·20
2	20/33	60·6	6·86 ± 2·03
3	20/47	42·5	6·98 ± 1·94
4	9/17	52·9	9·00 ± 3·52
5	14/21	66·6	13·87 ± 3·06
6	24/36	66·6	15·38 ± 2·52
7	87/110	79·0	23·07 ± 1·49
8	21/24	87·5	25·94 ± 4·69
9	11/12	91·6	30·53 ± 4·75
10	14/14	100·0	33·98 ± 5·82
11	138/178	78·6*	40·22 ± 1·67
12 (M.O.F.)	98/138	*c.* 68·8*	39·49 ± 1·86

* See text.

The other part gives a further characteristic item, as the percentage of measurable contents increases (as might indeed be expected) with the average measurable consumption. In other words, the higher the general average consumption of poison bait in the samples, the smaller the number of rats which ate untraceable amounts. This again reflects to some degree a uniform attitude to the poison bait in the whole colony, even in those animals which could not be examined. The relationship is shown in Fig. 1 in which the percentage of measurable contents is plotted against the average consumption of poison bait shown with its standard error.

One sample falls short of the general trend. Sample No. 11 from the London sewers has the highest poison bait intake, but not as high a percentage of measurable stomach contents as would be expected. This is due to purely technical reasons. There was a great number of bodies to be dissected in a short time and many stomach contents of watery or slightly mixed consistency were discarded. With more time for examination the percentage measured in this sample would have been considerably greater as only five out of forty rejected animals had minute or no visible poison bait in the stomach. The same considerations are probably even more applicable to the sewer sample not examined by the writer (M in Fig. 1).

In conclusion, one is justified in saying that in the colonies examined the degree of eagerness to accept the bait was expressed both in the average amount consumed and in the distribution of individual acceptance.

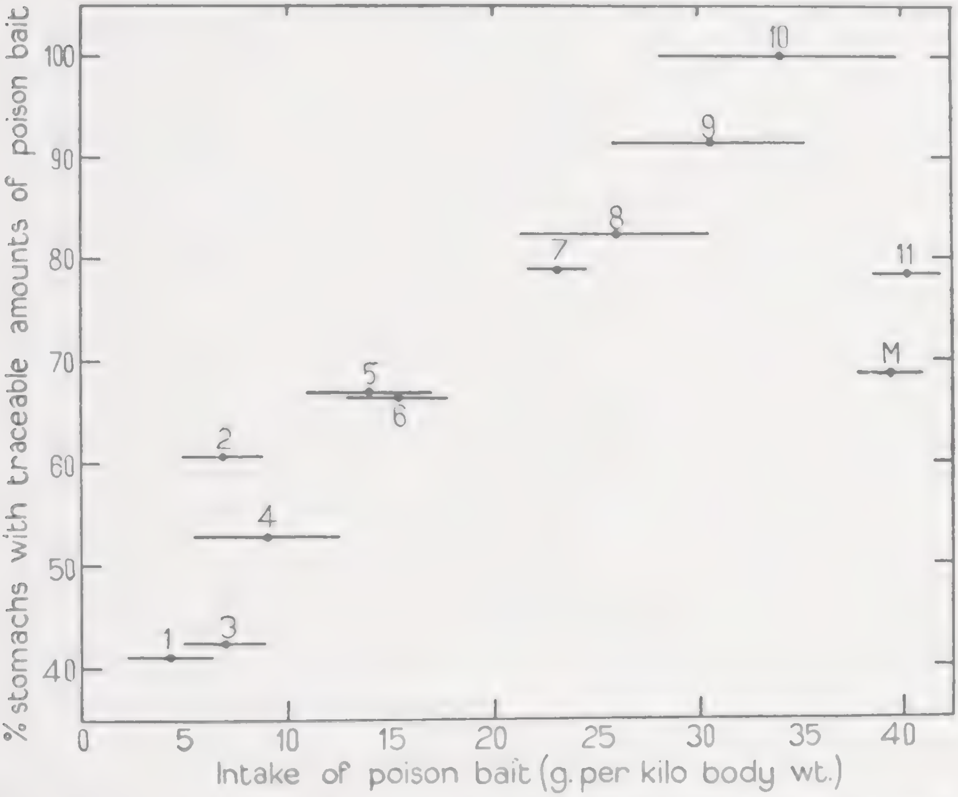


FIG. 1. Relationship between the amount of poison bait recovered from the stomachs of wild brown rats and the proportion of stomachs with untraceable amounts. The standard deviations of the mean traceable amounts of poison bait are shown by horizontal lines.

(iii) *Coefficient of variation.* An attempt to arrange the samples in groups of closer affinity was done on the basis of the coefficients of variation, this being the standard deviation expressed as percentage of the mean intake of poison bait per kilo body weight (($s/m \times 100$). Table 7 gives the samples arranged according to the decrease in the coefficient of variation.

It will be noticed that the relative variability of the amount of poison bait consumed (per kilo body weight), i.e. the coefficient of variation, tends to fall into at least three or possibly four main groups. Relative variability differed widely in the populations, the spread being much higher in the populations at the top of the table and decreasing towards the end.

TABLE 7. *Samples 1–11 arranged according to the coefficient of variation of poison bait consumption*

Sample	*No. of stomach contents measured*	*Mean consumption of poison bait (g. per kilo body wt.)*	*Standard deviation*	*Coefficient of variation (%)*
1	7	4·26±2·20	5·821	137
2	20	6·86±2·03	9·078	132
3	20	6·98±1·94	8·676	124
4	9	9·00±3·52	10·560	117
8	21	25·94±4·69	21·492	83
5	14	13·87±3·06	11·449	83
6	24	15·38±2·52	12·345	80
10	14	33·98±5·82	21·776	64
7	87	23·07±1·49	13·898	60
9	11	30·53±4·75	15·754	52
11	138	40·22±1·67	19·618	49

(*d*) Relation to field operations

A general survey of all data collected remains to be done. Three criteria for arranging the evidence into ordered schemes were adopted:

(*a*) The mean amount of poison bait consumed in each colony expressed in g. per kilo body weight.

(*b*) The percentage of animals in each campaign, in which the poison bait could be measured.

(*c*) The coefficient of variation of poison bait consumption.

The samples were initially numbered according to the increase in average intake of poison bait. If one arranges these samples according to the remaining criteria the distributions in Table 8 are obtained.

TABLE 8. *Samples 1–11 according to different criteria of consumption of poison bait*

Criterion	*Samples (lower lines) in progressive succession*			
Mean consumption of poison bait (g. per kilo body wt.)	< 10 g.	*c.* 15	> 20	> 30
	1 2 3 4	5 6	7 8	9 10 11
Measured samples (%)	40–60%	> 60	80 and higher	
	1 3 4 2	5 6	11 7	8 9 10
Coefficient of variation (%)	> 100%	*c.* 80	< 70	*c.* 50
	1 2 3 4	8 5 6	10 7	9 11

The following values are associated with the different groups of samples:

(*a*) Low average intake of poison bait	< 10 g. per kilo	Nos. 1, 2, 3, 4
Low % of measurable stomach contents	40–60%	
High coefficient of variation	> 100%	

(*b*)	Medium average intake of poison bait	*c.* 15 g. per kilo	Nos. 5, 6
	Higher % of measurable stomach contents	*c.* 66%	
	Coefficient of variation	*c.* 80%	
(*c*)	High average intake of poison bait	> 20 g. per kilo	Nos. 7, 9, 10, 11
	High % of measurable stomach contents	*c.* 80% and higher	
	Coefficient of variation	< 70%	

Sample No. 8 does not fit into these schemes. This sample belongs to the last category in average poison bait consumption and percentage of measurable stomach contents; but to category (*a*) in coefficient of variation. As shown below environmental conditions were abnormal during this campaign.

These three groups represent steps in a succession, where the average consumption of poison bait rises, animals with unmeasurable poison intake become less frequent, and variability tends to decrease.

It is noticeable that the success of the campaigns, as judged by the operators, increases in accord with the data from the examination of stomach contents (Table 9), i.e. with the increase of average consumption of poison bait, and percentage of measurable contents, and with the decrease of the coefficient of variation.

Samples 7 and 11 are very similar in the general tendency of distribution; but the background is totally different: sample 7 represents a farm population with very good food conditions. In this sample there is a certain small number of animals between 200 and 400 g. body weight with smaller consumptions. In these cases smaller amounts of poison bait are usually accompanied by presence of fresh food in the stomach. The campaign was a success because of the good technique of interception by the operator. Sample 11, from the London sewers, is a very good example of an adequate technique backed by food conditions favourable to prebaiting and conditioning. Those two samples apparently represent populations which, although differing from each other in the intensity of poison bait approach, behaved with a certain uniformity within each colony.

Another group (samples 8, 9, 10) had a very scattered but on the whole high spread of poison consumption. Samples 8 and 9 contained a small percentage of unmeasurable animals, sample 10 had none. Samples 9 and 10 were from successful trials, and it is understandable that with such high intakes all the bodies in sample 9 were picked up within 3 hours. In No. 10 prebaiting for 12 days and the application of 2% zinc phosphide gave a high poison bait consumption in spite of very good food conditions inside a wheat-rick. Sample 8 represents a failure from the operator's point of view, only a small number of animals of a rubbish dump being conditioned; but those were eating large amounts. This was a shifting population because of a fire driving the animals from their usual places.

The remaining group represents on the whole smaller populations with low intakes. In samples 1, 2, 3, and 4 a large proportion of the population

TABLE 9. *Comparison of field data and results of stomach analysis*

Sample No.	*Environment*	*Treatment A = previous B = present*	*Estimated success of campaign*	*Poison bait consumption (g. per kilo body wt.)*	*% of measured stomach contents*	*Coefficient of variation %*	*Remarks*
1	Straw-rick, banks	*A* ? *B* 1 day prebait	*c.* 70%	< 10	40–60	> 100	Two populations mixed
2	Ricks, wheat mostly	A arsenic and zinc phosphide *B* 1-3-5 prebait	Failure				'Shy population'
3	Wheat-ricks	*A* rodine and arsenic *B* 1-2-3 prebait	87%				'Residual population'
4	Hedge, ditch	A ? *B* 1–3–5 prebait	Doubtful				Food habits not broken
5	Rubbish dump	*A* ? *B* 1 day prebait	80–90%	*c.*15	*c.* 66	*c.* 80	Short prebait
6	Barn, oats	*A* ? *B* 1-3-5 prebait	Success				Food conditions good
7	Farm	*A* not recently *B* 1-3-5 prebait	97%	> 20	80–100	*c.* 50–60	Good interception
9	Farm	*A* 2 months before arsenic in sugar-meal *B* 1-3-5 prebait	Success				Killed in 3 hrs.
10	Wheat-ricks	*A* ? *B* 12 days' prebait	96%				2% zinc phos. long prebait
11	Sewers, London	*A* none *B* 4 days' prebait	Success				Poor natural food conditions
Not fitting into above scheme:							
8	Rubbish dump	*A* several *B* many days' prebait	Failure	25·94	87·5	83	Dump fire shifting population?

consumed insignificant amounts and three of these campaigns (Nos. 1, 2, and 3) were regarded by the operators as failures. An analysis of the situation gives the following explanation: samples 2 and 3 were from previously treated populations, one was described as 'generally shy' and the other was a residue after arsenic. Sample 4 was from a population living in standing corn, and judging by the consumption had not been well enough conditioned. Sample 1 was a mixture of two populations, the treatment of which was moderately successful in one but a failure in the other. These four samples represent typical pictures of more or less unsuccessful campaigns, and stomach analysis has supplemented the opinion of the operators. In the two populations Nos. 5 and 6 the distribution of individual bait consumption is not scattered, the intake per kilo body weight is much higher than in the previous group and both were fair successes.

In addition, there was the sample from a treatment of the Paddington sewers by the M.O.F. These sewers had already been treated in a general campaign 12 months earlier and partly recolonized since. This operation was again conducted with 4 days' prebaiting and a final application of 5% zinc phosphide in rusk. The poison consumption in relation to body weight is strikingly similar to that in the earlier sewer sample.

4. CONDITIONS OF BAIT ACCEPTANCE

Factors which determine the acceptance of poison bait can be grouped roughly as (1) *external*: food, cover, amount of disturbance in the environment, efficiency of materials and methods employed in control, and (2) *internal*, consisting of various elements of rats' behaviour, their rhythms and speed of feeding, conditioning to places and baits, distraction and physiological factors such as diet and hunger. The action of these factors may be expected to vary between colonies, but to become secondary after a certain time to the onset of illness caused by the poison. In treatments where a first campaign has left a residual population there is often a new factor consisting of various forms of bait-shyness. We now have to examine the factors shown by stomach analysis to be important.

(*a*) External factors

The distracting influence of the normal food is important, as in many habitats rats have established feeding habits which it may be difficult to change. In several instances besides those already discussed much normal food was found in the stomach and prebaiting had obviously failed to ensure that a large amount of poison bait would be eaten. In sewers, on the other hand, food often appears to be scarce and may be a limiting factor to population size. Additional food supplies are therefore readily attacked and stomach contents showed an excellent response to the baits.

Control methods cut across the animals' habits by conditioning them to visit baits at certain sites or by interception or both. Control operations demand skill and knowledge of the environment and habits of the infestation. The attractiveness of baits and way of distributing them, and the efficiency and palatability of poisons are of obvious importance, also the time of baiting. In one case poison bait was poorly consumed because it was laid down too late in the evening: for the rats must find it before they satisfy their hunger elsewhere.

Stomachs of animals poisoned without any prebaiting contained widely different amounts of poison bait and a greater percentage of untraceables than those from campaigns with prebaiting.

As a contrast to the poisoning of the wheat-rick in sample 10, 2% zinc phosphide in rusk was used without prebaiting in a pea-rick in the next field but one. Fourteen corpses were examined in each case, and traceable amounts of poison bait were found in all the rats which had been prebaited but in only five of those directly poisoned (Table 10).

TABLE 10. *Amount of poison bait in the stomachs of rats poisoned without prebaiting*

(*2% zinc phosphide in moist rusk*)

Wt. of rat (g.)	225	315	340	350	460	30–200
Poison bait (g.)	0·3	3·4	9·1	6·6	8·9	0 (9 rats)

(*b*) Response of the animals

The response of the animals to the situation created by environment and methods of control is primarily dictated by their physiology. Privation of food, within certain limits, increases the general activity of the rat, according to animal psychologists (Munn, 1933, p. 72). Diet may have a similar effect. It is known from maze experiments that hunger increases the straightforward drive towards a food goal, whereas satiation increases idle exploring and strolling about (Katz, 1937, p. 158).

In some colonies day-time activity has been observed. This is important from the point of view of control measures. The time when poison bait is placed may decide how well it is taken, as any previous feeding may decrease the state of hunger and eagerness of approach. If poison bait is laid down before feeding starts, only digested food, if any, should be found in the stomach of well-conditioned rats. This whole complex question could not be examined in detail, but its importance may be shown from one example. In sample 7, apart from considerable quantities of poison bait, only digested grain with no starch content was found in most stomachs: obviously from a meal some hours before. However, the stomachs of fourteen animals out of 110 contained fresh food consumed immediately before the poison bait; and in all these cases the amount of poison bait was small or untraceable.

The state of satiation may not only determine the approach to the bait but the emptiness or fullness of the stomach may have some influence on the action of the poison inside the body; there are, however, no observations on this.

The action of poisons is manifested outwardly by symptoms of illness, which 'warn' the rat and feeding stops (Ch. 8). However, it would not be advisable to apply the times found with white rats under laboratory conditions except as rough indicators of field conditions. It seems that symptoms may sometimes appear earlier in the field (Ch. 4, § 15 (*a*)), especially with the movements and intermittent feeding usually displayed by wild rats. There may also be differences in feeding intensity.

Feeding behaviour was watched in experiments on wild colonies accustomed to feeding on wheat. When the bait was changed to flour it was first approached cautiously and only later on eaten normally (Chs. 4, 5). Dry bread-crumbs were decidedly less familiar: out of eleven rats seen only four began to feed in the first 5 minutes. As shown in Chapter 7 different foodstuffs are consumed at different speeds, which is of importance for the consumption of poison bait.

As a rule feeding behaviour, including rate of initial feeding, duration, and time of starting, depends on the amount of natural food and on the prebaiting methods (surplus or token). According to the habitat and available food we may expect a range of difficulties in conditioning rats, and in consequence a varying consumption of prebait, or poison bait. Token baiting failed to produce rapid feeding in a small residual population (Chitty and Shorten, 1946). A change of bait often results in a change of feeding behaviour (Chs. 4, 5, 7). Therefore, the sudden application of an unfamiliar poison bait will cause 'inspections', sampling, and refusal.

In large samples of corpses there were a few individuals which had not followed the general trend of approach to the baits. Such individual behaviour sometimes appeared even in cage experiments on white rats but was more pronounced in wild rats, especially in small colonies and amongst such animals which had already been affected by control or other operations.

Finally, rats' behaviour towards poison baits is determined by previous experiences with poison which may influence the approach to and consumption of further baits. In one test, at least, there was a suggestion that animals over 400 g. had taken abnormally low amounts of poison bait compared with the rest of the colony. These animals may well have been survivors from a long series of campaigns which had ended 4 months before.

(*c*) Discussion

This examination of external and internal factors which determine the consumption of poison bait leaves no doubt that there must be differences between colonies. Some statistical criteria were evolved from eleven samples of treated populations and broader conclusions were sought for investigating this complex problem.

In well-conducted operations under favourable environmental conditions rat populations other than those just recently treated are expected to respond well to prebaiting and poisoning. With disturbing environmental factors more or less eliminated, such initial treatments will produce a certain uniformity of response from the population because the purely physiological elements of bait consumption appear with greater clarity. Such populations will show, therefore, a relation between body weight and intake of poison bait, which most rats eat like ordinary food until symptoms of uneasiness and illness stop further feeding.

Such populations may also be expected to conform to the higher range of the three criteria evolved in this paper. Samples 7 and 11 are good examples and also the sample from the M.O.F. Sample 7 represented a population from a farm with good alternative food supplies, but with rats well intercepted by hole baiting, whereas the London sewers represent an environment where conditioning to the sites and baits was apparently not difficult. In sample No. 12 about 39% of the 138 rats had poison bait filling or almost filling the stomach, which shows the intensity of feeding in many of the rats, and the good conditioning with rather poor alternative food supplies present. Feeding must have been a veritable race of appetite against the onset of symptoms of illness.

Populations with a recent experience of poison offer a different picture. We know that survival of poison mostly produces a changed attitude towards successive poison baits, ranging from general avoidance to a more or less tentative approach, restricting the consumption of poison bait. Samples 2 and 3 are instances where the 'normal' behaviour of the animals seems to have been overlaid and depressed by some additional factor; this is especially clear in the higher weight classes with their very restricted consumption and the large percentage of animals which ate untraceable amounts.

These are the two extremes in the samples examined, in between which lie transitional or intermediate results, reflecting the varying conditions and responses of the colonies. Each sample represents a different intensity of bait approach as seen from the different mean intakes of poison bait in each sample. This is probably due to the different initial speed with which the animals attacked the bait; the final decisive factor of warning symptoms is most likely to be fairly uniform. It should be added that even in 'normal' populations some individuals deviate from the general pattern. One should not expect highly organized animals to respond with complete uniformity to all factors of a campaign.

There is one major objection to the present methods and conclusions. The rats picked up were only an unknown fraction of the total kill (Ch. 4, Fig. 9). Some of our results might have been different if all the dead rats could have been examined. Present conclusions may be based on those rats which took most poison bait—though animals with untraceable intakes must obviously be close to that category which ate sublethal doses.

It seems that by developing the method of stomach analysis and by securing more results of tests done by well-devised methods in known environments with different baiting systems and poison baits, a great amount of valuable information could be brought together. It should be possible in this way to analyse much more clearly than is yet possible the reasons for a differential poison bait acceptance, and to define more precisely the interplay of some of the main factors leading to failure or success. But within our samples the results of stomach analysis were largely consistent and illuminating and gave an idea of the amounts of poison bait consumed. The data on stomach analysis reflected the outcome of the campaigns with all their implied complexities, i.e. the animals' response to the operators' methods against the background of all other conditions. It appears that the approach to and the consumption of poison bait is not a pure chance action, but one in which the factors can be investigated and analysed.

5. EARTH IN THE STOMACH

Laboratory rats which were poisoned ate litter, pellets, and even rust, almost regularly (Ch. 8). It was thought that this earth-eating reaction might be an innate or acquired attempt to neutralize stomach discomfort. In many of our field samples of brown rats earth was discovered as the last item to enter the stomach. It seems that this is a widespread phenomenon, the significance of which can only be guessed.

In connexion with the earth-eating of laboratory and wild rats after poisoning, a few remarks found in literature may be quoted on protective agents against poisons. Schwartze (1920) mentions that whiting (calcium carbonate) protected rats and mice against the poisoning effects of barium carbonate as well as lead carbonate (these observations are quoted from an earlier source). McDougall (1944) quoting the same reference says: 'Although such references in literature are rare, the concept that on occasions certain foods protect rats from poison is freely discussed by some of those interested in the control of rats in Queensland canefields. . . .' The author produces a table (No. 9) showing that *R. conatus* fed on sugar-cane previous to poison testing 'showed improved intakes of barium chloride but the intakes were never lethal'. The same author remarks on arsenic (p. 11). 'Large amounts of arsenic may be taken by some rats in weak poison mixtures, either at one feed or over a period, without causing death.' On thallium sulphate he gives the following remark (p. 28): 'The accumulative action of the poison depends on a time × dosage factor. Doses less than 20 mg./kg. given on successive nights over a six-day period will not kill. The animal can apparently eliminate from its system sufficient of the poison in a 24-hour period to keep alive. . . . With intermittent feeding an occasional poison intake approaching the lethal dose can be eliminated by the animal. The sum of poison intakes on successive nights may be greater than the M.L.D. without death occurring.'

The problem of self-protection against poisons is taken up by Hatcher and Weiss (1923, pp. 140–1) in their studies on vomiting:

> . . . We believe that the rat or its ancestors lost the capacity for vomiting through the development of processes that afforded better protection at the time that the change took place, and we know that this animal has retained its capacity for reacting towards many poisons with the more primitive function of nausea. . . . Many rodents have the capacity for selective absorption from the gastro-intestinal tract, whereby certain soluble poisons are absorbed slowly, or not at all. . . . Many rodents also have the capacity for excreting or destroying certain poisons after absorption to a far greater degree than the cat, dog or man. This is not a universal rule but numerous examples of it might be cited from our own

> experience and from literature.... Animals don't eat during nausea. Above a certain threshold of the introduced emetic or nauseant, the pylorus of the stomach closes and stays closed until nausea is finished, though this is not always a perfect arrangement. This stops the unpleasant stuff getting from stomach to inter-stomach.

The authors think that nausea may give protection against sub-lethal doses of strychnine.

6. SUMMARY

1. The stomach contents of a rat killed by poison give some information about the amount of bait and previous food consumed. Control tests on white rats have proved that the quantities of certain poison bait recovered from the stomachs correspond fairly well with the amounts gone from the feeding trays.

2. Brown rats from various field campaigns have been examined. The present report deals mostly with results obtained from twelve field trials, conducted with 5% zinc phosphide in moist rusk, and one with 2%.

3. In wild rats a large consumption of poison bait is mostly correlated with the presence of little or no other food in the stomach contents; small or untraceable amounts of poison bait with the presence of other food. This shows the importance of conditioning by prebaiting.

4. Different colonies of rats approach a poison bait differently, as seen from the differences in the average consumption of poison bait per kilo body weight. In most of the samples a varying number of rats had unmeasurable amounts of poison bait in the stomach. The percentage of those measured was found to be related to the average consumption of poison bait (in g. per kilo body weight) in each colony. The higher the mean intake the higher also the percentage of measurable contents.

5. The average consumption and the percentage of measurable stomach contents show the intensity of consumption and the distribution of individual acceptance of poison bait in the sample killed and recovered. This sample may have included disproportionate numbers of rats with high intakes.

6. In large samples from campaigns, recorded as successful, a relationship was determined between the individual body weight and poison consumption. Consumption increases absolutely with the body weight but is relatively stable per unit body weight.

7. Stomach analysis has brought forward three criteria of a statistical nature: the average intake of poison bait, the percentage of rats with measurable poison bait contents, the coefficient of variation of individual poison consumption.

8. In most of the samples all three criteria of poison bait consumption were found to be correlated with each other. These criteria were also related to the success of the campaigns, as estimated by the operators.

9. The results of the analysis of stomach contents reflect the success or failure of campaigns, conducted with zinc phosphide in moist rusk. Consumption of poison bait is not a pure chance action, but the outcome of the action of many factors, some of which are indicated.

REFERENCES

Chitty, D., & Shorten, M. (1946). 'Techniques for the study of the Norway rat (*Rattus norvegicus*).' J. Mammal. 27: 63–78.

Hatcher, R. A., & Weiss, S. (1923). 'Studies on vomiting.' J. Pharmacol. 22: 139–93.

Jaffé, R. (1931). 'Anatomie und Pathologie der Spontanerkrankungen der kleinen Laboratoriumstiere. . . .' 832 pp. Berlin.

Katz, D. (1937). 'Animals and men. Studies in comparative psychology.' 263 pp. London.

McDougall, W. A. (1944). 'An investigation of the rat pest problem in Queensland canefields: 3. Laboratory experiments on food intake and toxicity.' Qld J. Agric. Sci. 1, No. 3: 1–32.

Munn, N. L. (1933). 'An introduction to animal psychology: the behaviour of the rat.' 439 pp. Cambridge, Mass.

Schwartze, E. W. (1920). 'Toxicity of barium carbonate to rats.' Bull. U.S. Dep. Agric. No. 915: 1–11.

10

RURAL RAT CONTROL

By A. D. MIDDLETON

I. RAT CONTROL BEFORE 1940

It is probably true that before 1940 most farmers and other residents of rural areas were indifferent to rats. This state of apathy can be attributed to many causes and there is no doubt that during the period 1920–40 much of it was due to lack of money in the depressed agricultural industry. When the farmers were getting such low prices for their cereal crops, and often found difficulty in selling them at all, there was little stimulus to stop rats eating them.

On the more progressive (or heavily infested) farms, particularly in eastern England, serious attempts were made to reduce the rats by employing expert rat poisoners who specialized in farm rat control. In Norfolk several men adopted rat-killing as a full or part time occupation and two or three of them concentrated on farm contracts. The normal charges for one complete service over a farm was about £1 per 100 acres or slightly less on the large farms. The methods used were similar with most operators: 2 days' prebaiting with a sugared meal mixture and poisoning with arsenic. The meal mixture varied considerably, often containing barley meal and malted barley as well as wheat meal. Sugar was generally used in rather high proportions (15–30%) and most operators had their own secret ingredients such as aromatic oils. Arsenic was used at between 15 and 25% and was often hand-ground from white rock arsenic. Most farms contracting with these operators got one treatment a year, during the winter or spring, but in some cases autumn and spring treatments were carried out.

A more widespread practice, especially in East Anglia, was poisoning by the gamekeepers on estate partridge shoots. In north Norfolk a large proportion of the farms received treatment in this way, invariably by the sugar-meal-arsenic method. Most gamekeepers, being concerned only with the rat as an enemy to game-birds' nests, poisoned in the early spring, when most of the damage to farm crops had been done. Field and hedge-bank infestations, which are so common in East Anglia, naturally received more attention from keepers than farm buildings and corn-ricks, where the rats were not a source of immediate danger to game-birds' nests.

A few of the big servicing companies had contracts on farms and other units in rural areas but these formed a very small proportion of the total. Organization and travelling costs made rural work must less profitable than urban infestations.

The remaining action was that of the occupier who himself put down poison, usually a proprietary brand bought locally, or did occasional trapping or gassing. Without experience and efficient methods little permanent good was done.

It is not surprising therefore that farm rats attained very high numbers in some areas of Great Britain during the period 1920–40. It is regrettable that during this period there were no population studies which would have provided evidence about the extent of the reduction due to organized control in 1940–1. Some indication of the high pre-war infestations can be gleaned from the evidence of first treatments in 1940–2. In the following examples the work was carried out by operators of the Gloucester County Council (Nos. 1–5) or the Oxfordshire W.A.E.C. (No. 6), often in conjunction with members of the Bureau, who carried out the other three treatments.

(1) February 1939. Small poultry farm near Winchcombe, Gloucestershire. Poultry houses were raised, holes dug out, and rats killed by dogs. 150 killed first day and over 80 on each of following 4 days: total over 470. (2) 1940. Farm near Cirencester, Gloucestershire. At threshing in January an average of 60 rats was killed in each of several ricks. 330 rats were trapped that autumn. (3) September 1941. One set of farm buildings at Fosse Cross, Gloucestershire. Over 700 rats killed during threshing and moving bales of hay and straw. (4) July 1942. Three farms at Hinchwick, Gloucestershire. 327 rats trapped around five corn-ricks in one field. 211 picked up round farm buildings after zinc phosphide. (5) April 1942. Group of three farms at Barrington, Gloucestershire. 1,271 trapped in 18 days. (6) December 1942. Farm premises near Burford, Oxfordshire. 395 rats picked up after zinc phosphide. (7) June 1942. Baled straw at Buckland, near Broadway, Worcestershire. 379 dead rats found after direct poisoning with zinc phosphide and 27 more killed by dogs (Plate 2 (*a*)). (8) September 1942. Farm premises near Burford, Oxfordshire. 119 rats picked up after zinc phosphide. (9) June 1942. Farm premises near Great Tew, Oxfordshire. 120 rats picked up after zinc phosphide.

The number of rats killed in threshing ricks at Compton from 1939 to 1942 (§ 5) also illustrates the degree of infestation common at that time. There is no doubt that similar or even higher infestations existed in many other parts of the country.

2. ENVIRONMENT

The rural environment of rats is probably more diverse than the urban, since it includes hedge-banks and corn-ricks remote from any human habitation as well as farm food stores, village shops, and knackers' yards. There were even buffer depots (Ch. 4, § 6 (*b*)) in strictly rural surroundings, and several types of factory. Sugar-beet refineries, creameries and cheese factories, bacon factories, and canneries have increased enormously during the past twenty years and must now be regarded as permanent features of the rural environment.

It might be argued that the available food on the farms has decreased considerably during the past twenty years, as less stock food is kept in store, and cereals grown on the farm are removed quickly by modern marketing arrangements. Combine harvesters are rapidly decreasing the need for stacking corn unthreshed in the fields and more intensive methods of stock management and housing give less support to large rat colonies. With the exception of combine harvesting and improved stock housing, however, it is doubtful whether these factors have an important influence on the total rat population. On the average farm there is still plenty of suitable food and cover to support large populations.

On the other hand, the large acreage of sugar-beet in some areas and the great increase in cereal crops during the war provided more food in the fields than during the depressed farm conditions of 1920–40. On the whole, therefore, the rural environment is neither more nor less favourable to the development and survival of large rat infestations than it was twenty years ago; but there may have been a considerable regrouping owing to the change in available habitats.

In this chapter, so far as possible, we shall confine our attention to farms as the basis of the rural rat problem, regarding the rural factories, village shops, and backyard hen-runs as identical with their counterparts in urban areas. This distinction broadly coincides with that made by the M.A.F. in the administration of rat control through the county W.A.E.C. on farms, and through the local authority on urban property.

There are many possible habitats for rats on farms, some permanent, others available for short periods or seasonally. They may be classified roughly as follows.

(*a*) Farm buildings

Any farm building where foodstuffs are or have been stored, or where animals are housed or fed, is likely to harbour rats. A set of farm buildings servicing a large (500 acre) farm in Oxfordshire may be taken as one example. These premises were heavily infested before the first complete poison treatment when 120 dead rats were picked up after poisoning with zinc phosphide. These farm buildings are built entirely of stone, most of the walls being very thick with a loose stone rubble centre. Such walls, unless kept in first class condition by cement pointing, form an almost perfect harbourage for rats as they can easily mould runways and nesting sites throughout the loose centres. Many rats lived permanently in these stone walls, which formed convenient homes adjacent to any source of food that happened to be in or near a building. It is useless to stop up the regular holes in these walls as the mortar is so softened by age that rats can soon scratch in or out at a new point.

This condition is typical of many old farm buildings—and most of them are old—in all parts of the country. Very few farms have buildings which provide no possible harbourage for rats, and even the most modern concrete buildings are rarely made inaccessible to rats feeding in them but living outside. It is, indeed, a very difficult job, conflicting with normal farm management, to make and maintain buildings absolutely rat-proof. On the other hand, any new building of concrete, brick, and metal can be designed not to provide accommodation for rats within its structure. It greatly simplifies rat control if all sources of infestation are outside the buildings because of extreme tidiness and lack of permanent cover inside. To achieve this, however, entails very frequent movement of all stored material such as sacked grain and meal, cattle and poultry feeding stuffs, chemical fertilizers, corn sacks, chaff, and the various equipment and constructional goods. The attitude, ability, and income of the farmer, and the number and quality of his workmen naturally have a most potent influence on this form of habitat control. In considering the most efficient methods of rat control on farms, it is generally agreed that it is impracticable to expect rat proofing to eliminate farm rats, although every effort should be encouraged to simplify control by limiting cover, especially inside buildings.

On the farm under discussion many rats used outside cover, such as wood piles and earth buries, as well as the interior wall system. The earth buries were very well established at both ends of a culvert running under the farm buildings to a derelict mill-wheel. There is no doubt that rats used both ends of this culvert in large numbers and were particularly numerous in the pit of the old water-wheel. These rats around the barn and water-wheel were feeding from an abundant store of unprotected grain and other foodstuffs in the barn. Most of the corn crops were stored before threshing in the Dutch barns at either end of the premises. These were invariably invaded by the rats and large populations developed.

A very different type of infestation was found on a farm where a modern concrete dairy cattle unit provided the food supply for the rats but no harbourage at all. A large number of rats came from an extensive bury system on the edge of a wood 20–50 yds. from the buildings, which they entered through doors and drains to feed in the cattle mangers at night, or when there was no human disturbance. It is clear that complete rat-proofing of such a building would be possible by providing shutters to drains and keeping doors closed and tightly fitting. In practice, however, the doors were left open most of the day, and all night during summer, to dry out the washed floors and ventilate the buildings. These rats were easily poisoned in the buries and a new population never became established there. A plan of another farm is given in a bulletin of the M.A.F. (1945).

A common type of infestation centred on buildings is found in field barns where corn is stacked. These barns may be either stone or wood and usually have a cattle yard attached for wintering bullocks. On more modern farms they are superseded by Dutch barns. Unthreshed corn is stacked in them and often left until early spring, by which time it harbours a good stock of rats. Many rats invariably escape at threshing, especially through holes in the walls, and remain around the buildings during the spring, living on the threshing remnants and green plants or the feed for cattle in the yard. In the summer they move up the walls or hedges from the barn and live in the growing corn and root crops until harvest, and return to the stacked barn for the winter. From such a centre many rats naturally spread to field corn-ricks or other buildings.

Piggeries and poultry houses, spaced at some distance from the main farm buildings, often become infested with rats, especially when careless feeding provides waste, or dry mash hoppers are in constant use. In piggeries it is difficult to avoid providing food for rats, since they can feed from the troughs at night. They also live readily in heaps of pig manure.

(*b*) **Corn-ricks**

The British system of stacking grain for periods of several months before threshing has certainly encouraged rats on farms. Not only does the rick provide ample food and cover for a large number, but the combination of these two factors enables rats to breed successfully throughout the winter months (Venables and Leslie, 1942). The types of rick and methods of stacking vary considerably throughout the country, but there are few farms of any size which do not stack unthreshed corn in some way. Even on the highly mechanized arable farms with combine harvesters, there are generally one or two crops of oats or wheat which have to be stacked. A normal mixed farm of, say, 300 acres, with about half the land grass, will have about 12–15 large ricks of corn after harvest. Other facts about the corn-rick habitat and its rat population will be found in Chapter 11.

The extent of infestation in corn-ricks naturally depends a great deal on the number of rats in the surrounding country-side and on the choice of site. Rick sites can be roughly grouped as (1) isolated ricks or groups of ricks away from any farm buildings, (2) rickyards adjacent to farm buildings, (3) Dutch barns, some isolated but often with cattle yard or other buildings, or (4) old field barns, usually with cattle yard (Plates 2, 5, and 6). Any infested corn-rick is likely to leave behind a more or less permanent colony of survivors after threshing. This applies to isolated field ricks as well as to those near or inside buildings. Rats often make burrows in the nearby ground, particularly in a ditch or hedge-bank, and may survive, breed, and infest the next season's ricks. In some ricks the rats develop their runway system mostly at the base of the rick, while in others they start at the top just under the eaves and may remain and build up an infestation in the top alone with no holes at ground level. Between these extremes other ricks have rats both at the top and bottom, but more rarely (except in very heavy infestations) in the central position. These differences in habit affect poisoning procedures, as described later.

The different types of grain show a differential infestation on the average, wheat-ricks carrying a higher population than barley and oats (Ch. 11, and § 5). It is not clear whether this is due to a preference for wheat as a food or to differences in nutritive value of these three common cereals. Ricks of beans, peas, linseed, or rye often hold rats in considerable numbers.

(*c*) Sites of threshed ricks

Since the corn-rick is probably the most effective breeding site for rats on farms, dispersal from the site after threshing is one of the most serious ways in which heavy infestations are developed elsewhere. The erection of a rat-proof barrier round the rick at threshing (Plate 2), and the killing of escaping rats is now a legal responsibility of the threshing contractor, owner of the rick, and occupier of the land (Rats Order, 1941) and most of the rats from infested ricks are killed at threshing when this law is carefully observed. It has not, however, proved an easy matter to enforce this law and there is no doubt that many ricks are still threshed without fencing (especially when there appear to be rather few rats present) or the fencing in inefficiently erected and maintained during the operation. On many rick sites, in barns, close to buildings, or with earth buries in an adjacent bank, it is impossible, with any type of fencing, to kill all the rats at threshing.

The baled or loose straw, cavings, and other refuse usually left on the site after threshing give ample cover for the residual rats and enough food to maintain them for a few weeks. From corn-ricks threshed in the spring (when most of the heavy infestations are found) the rats can usually survive on the site until growth of crops in the surrounding fields gives them a plentiful summer food supply.

It is obvious that, failing the complete extermination of the population in a rick at threshing time, the period shortly after threshing is one of the most important for a strategic attack on the rick sites. If all these rats are killed there will be a great reduction in the stock available for summer breeding and infestation of buildings and ricks in the following autumn.

(*d*) Hedge-banks and fields

In a few parts of the country where arable farming has been dominant for many years—East Anglia, parts of Northumberland, and southern Scotland, for example—a considerable population of rats lives in hedge-banks and other open sites all the year round. Although these rats are apparently part of a general high population covering buildings, corn-ricks, and other normal sites, it is not uncommon to find a farm in Norfolk where the main buildings are comparatively free from rats while thousands live in the hedge-banks and corn-ricks on all parts of the farm area. On outlying hedge-banks on a farm in Norfolk during January and February 1942 takes of about 2 kg. wheat, representing about eighty rats, were recorded from eleven P3s covering only a small sample of the farm. Hedge-banks on other farms in this area were heavily infested at the same time, in spite of a continuous period of hard frost and snow. This type of infestation is common to most of north Norfolk and many other parts of East Anglia and is quite distinct from the local hedge-bank colonies in the Midlands, which are nearly always associated with some source of food, such as in ricks or buildings.

On many of the Norfolk hedge-banks it is difficult to see any readily available food in late winter, particularly in February, when most of the fields are ploughed and the only crops left are clover and grass leys or a few remnants of roots and kale. Since 1939, at least, many north Norfolk farmers have threshed with combine harvesters so that there are comparatively few ricks on some areas; but rats are still plentiful. On the other hand, sugar-beet probably has a pronounced effect in providing food fairly late in the winter; during the last few years a very large acreage has been grown in Norfolk—up to a third of the area of many farms. The method of harvesting sugar-beet provides a good deal of food for rats in the fields during late winter. The crowns of the roots, with leaves attached, are cut off and left on the ground. Rats eat these crowns readily and, as they do not decay quickly even when ploughed into the soil, they last for several months—often up to February or March.

Rats certainly appear to be quite numerous around the old sugar-beet fields in Norfolk during late winter; but there is little evidence that the development of sugar-beet growing in Norfolk is the main reason they live in the field-banks. Rats have been numerous in the banks in these areas for years and there are many localities with plenty of rats but no sugar-beet. The winter climate in Norfolk is generally colder, though with lower rainfall, than the Midland area, where rats do not normally stay out in the hedge-banks in large numbers. It has been suggested that these arable areas have developed a local race of rats which are adapted to living outside in winter.

The type of cover provided by the north Norfolk field-banks may be an important factor. These banks, earth ridges about 3–5 ft. high, usually with a small hedge on top, provide very easy burrowing; and rats seem to prefer a bank to flat ground. Extensive permanent rat infestations are also found in the banks of fenland dykes in Lincolnshire and the Isle of Ely, but rarely of the same high density which is normal in north Norfolk.

Although rats in other parts of the country appear more inclined to adopt corn-ricks and buildings as winter quarters, it must not be assumed that this is an invariable rule. In the bare stonewall country on the borders of Oxfordshire and Gloucestershire, for example, rats can be found living in the field walls at any time during the winter, remote from corn-ricks and farm buildings. Indeed it is doubtful whether rats completely leave the field-banks in any part of the country during winter, but there are few areas comparable to Norfolk. Rats are also frequently found in considerable numbers in old and occupied rabbit burrows.

(*e*) Root stores

The normal practice of storing root crops, such as mangolds, potatoes, and carrots, in clamps protected by layers of straw and earth, produces useful burrowing and feeding conditions for rats during the winter. Clamps often become infested and damaged, especially near farm buildings; but in the fields this does not invariably happen, even in the presence of a fairly high hedge-bank population. Potatoes are peculiarly variable in this way. Rats certainly eat them readily when stored in farm buildings and occasionally clamps are badly damaged, but they do not seem to be so commonly attacked as one would expect. In the Isle of Ely and west Norfolk during February and March 1945 no instances of potato-clamp infestation were found, although these clamps were the commonest feature of the countryside. Carrots and mangolds appear to be preferred to potatoes under these conditions of storage.

(*f*) Rubbish dumps

Rural district council or village dumps, where household refuse is deposited, are often sited in disused gravel, stone, or chalk pits surrounded by farm land. These dumps provide attractive food and cover for rats and many of them are heavily infested. There is very little evidence to show how far these refuse dumps influence the general rat infestation of the countryside in which they are situated; much depends on the alternative sites available. Under more urban conditions, such as on the Oxford City dump, it is probable that considerable interchange occurs between the dump population and various semi-urban infestations on allotments, pig, and poultry sheds near the dump. From dumps in strictly rural surroundings, there is no evidence that the rats spread into other habitats, although there is naturally damage to standing corn or corn-ricks adjoining these dumps. From the way in which some of these dumps become re-infested it may be that they attract rats from the surrounding fields and thereby reduce the infestation of the farm land. The same may be true of rural knackers' yards which provide harbourage without necessarily contributing emigrants into the farm lands if periodic control is exercised.

3. METHODS

The Bureau's war-time objective in rural rat control was to develop a system which could be guaranteed to give good results under all normal farm conditions when carried out by operators such as members of the Women's Land Army, who often came from offices or domestic life and received only a brief period of practical training. Although much rat destruction was carried out by experienced rat-catchers and poisoners no assumption could be made that all the operators had any previous experience or fieldcraft. The most economical use of labour and materials was also a basic factor influencing the type of control measures to be applied over the country as a whole.

This simplification of rat control involved many problems when applied to a large organization: (*a*) the use of a limited number of standard bait materials and poisons which were available in sufficient quantity without conflicting with human and animal food supplies or other war-time supply problems, (*b*) the reduction of the prebaiting period to the shortest possible time consistent with efficiency, to cover the maximum area with the labour and materials available, (*c*) the use of methods designed for speed and simplicity to make the best use of unskilled labour.

With these considerations in mind the method adopted for trial in rural conditions was 'hole baiting' with two prebaits. All the equipment needed is a long-handled spoon and a carrier for the bait. The type of spoon is important for continued efficiency: our experience has shown that the best is a strong dessert spoon, the handle cut off and the bowl welded to a metal rod $\frac{1}{4}$ in. diameter and 2 ft. long. The junction of the spoon and handle should be smooth and continuous, avoiding any protuberance which will catch in vegetation or on the edge of a hole. If the spoon is tied to a stick, bait is often spilled because the spoon is jerked when pushed through obstructions.

We have found the most convenient bait carriers to be tins or small buckets holding about one gallon or a little more. Some operators, especially cyclists, prefer fabric bags with a shoulder strap, but these are more difficult to clean than tins, especially after using wet bait.

'Hole baiting' is, in practice, a form of token prebaiting followed by poisoning in which large numbers of small baits are distributed throughout the area covered by the rats. A dessert spoon holds about 15–20 g. dry bait (*c*. $\frac{2}{3}$ oz.) or 25–30 g. wet bait (*c*. 1 oz.) and this is the normal amount used at each bait point, followed by the same amount of poison.

Most of the work on which our experience of rural hole baiting is based has been done with 2 days' prebaiting, but it will be clear that the method is also suitable for other periods of prebaiting or direct poisoning trials. The most thoroughly tested system which has been found to give consistently high kills is the '1-3-5' system (prebaiting on the first and third days, poisoning on the fifth day). This system has, therefore, been adopted as standard for Bureau poison trials on farms, and, because of its general effectiveness, has been widely used for farm rat control by government operators (M.A.F., 1945).

It is almost impossible to lay down anything more than general principles about the number and siting of bait points to ensure effective poisoning of an infestation, since this varies so much with the number of rats and the nature of the environment. It must depend in practice on the common sense and experience or training of the operator. The success of the work lies mainly in distributing the baits in such a way that every rat has an opportunity of eating sufficient of each prebait to arouse interest and of taking enough poison bait for a lethal dose with the minimum of effort and disturbance.

Theoretically, the most important feature of hole baiting is interception of the rats between their normal day-time resting places and their night-time feeding range. By baiting only in the holes occupied by the rats during daylight it is often possible to kill them without laying any baits on the feeding range. This is true of some simple habitats, such as a colony living in holes in a hedge-bank and feeding on a corn or root crop in the field; but in the majority of general farm operations it is extremely difficult to be sure of finding the day-time homes of all the rats and many may be living in cover without holes of any kind. In practice, therefore, 'hole baiting' consists of a mixture of true hole baiting, baiting under existing cover, and surface baiting. This is effective so long as the principle of interception is thoroughly adhered to and every effort is made to place baits in such a way that they will be found by rats before they reach their normal food.

The system of baiting the rats in their living quarters and diverting them from their habitual feeding range is also safe. By baiting in rat-holes and under other existing cover it is usually possible to place the poison baits well out of reach of domestic animals, farm stock, and poultry. Some farms, where large numbers of poultry have a free range, are not easy to bait satisfactorily without risk, if there are few well-covered points. Careful choice of site will usually overcome this difficulty, but in exceptional cases it may be necessary to construct a few artificially covered points. It is obvious from our knowledge of new object reaction (Ch. 5) that any such cover points should be constructed some time in advance of the baiting. In practice, however, the need for additional points may not be realized until the operator starts prebaiting. The best method then is to make covered points by very slight alterations to the existing cover, e.g. by moving stones or logs to protect part of a well-used runway but without obstructing it. Provision of 'new' cover, such as drain pipes laid in runs, tiles or boards set in the angle of walls, or tins and boxes put into new positions, must be avoided unless the start of prebaiting can be postponed for several days. The safest principle in this type of baiting is obviously to disturb the environment as little as possible during the whole operation, avoiding anything which is likely to make the rats shy or unsettled in their behaviour. The use of squill as a poison, in difficult cases with free ranging poultry, will naturally reduce the need for complete cover for all bait points.

Disturbance during the period immediately after laying poison baits in holes is probably an important factor giving rise to sublethal doses and shy survivors. Prebaited rats feed actively on baits placed in the holes at any time of the day, instead of waiting till evening or dusk as they normally do with surface baiting. This is particularly noticeable after prebaiting: the rats are often seen feeding on the second prebait or the poison bait (on the 1-3-5 system) within a few minutes. It is quite normal, when using zinc phosphide, to find several dead rats within 1 or 2 hours after laying the poison: for example, on 9 August 1942, four dead rats were seen at 4.50 p.m., less than 70 minutes after laying poisoned sugar-meal. By 6.40 p.m. twenty-three more corpses were found. The total number picked up dead was 120. Two prebaits had been used in this case. On 28 June 1942, a large area was poisoned direct with zinc phosphide in sugar-meal, between 3.15 and 6.15 p.m. In a walk round between 9.30 and 10 p.m., not covering the whole area, eighty dead rats were counted. A further 136 were found next day. It is clear that such daylight feeding activity is likely to be interrupted, especially by people, dogs, or cats, so that every effort should be made to leave the place as quiet as possible after the poison is laid; and where there is likely to be much disturbance, to poison late in the day. It is difficult to prove that these precautions are necessary, but it is logical to suppose that, if a rat is driven away after taking a sublethal dose, it may feel ill before it returns, and become shy of the bait.

The most common causes of failure on first treatments by hole baiting are undoubtedly an inadequate number of baiting points to cover the whole infestation and insufficient poison bait at important points, resulting in delayed feeding and later shyness. In the comparatively simple habitats such as hedge-banks in winter, open earth buries, or corn-ricks, the number of points to be baited presents little difficulty if every well-used hole is treated. Distribution is then automatically arranged to cover the infested area. In the more complex environments of farm premises the problem of correct distribution is much more difficult. The only safe policy under such conditions is to bait heavily in all sections, to make certain that wherever the rats are living they will get a chance of eating prebait and poison bait. Large and heavily infested groups of farm buildings in Oxfordshire and Berkshire were usually given 200–400 bait points. Some of the Norfolk rat-poisoners tend to use fewer points, while professionals in some parts of Gloucestershire, for example, use more, and there is a wide divergence in the habits of professional rat-poisoners on this point.

4. POISONING RATS IN CORN-RICKS

(*a*) Introduction

The destruction of grain in corn-ricks probably forms the major part of damage by rats in rural areas, while the ricks provide a favourable habitat for continued breeding throughout the winter. An efficient method of destroying rats in corn-ricks is therefore one of the most important factors in rat control in this country. The most successful rat-poisoners all admit the difficulty of dealing with the rats in these conditions and up to recent years there has been no serious attempt at organized control in ricks over large areas.

Various methods were suggested and adopted in the past either for preventing the rats from getting into corn-ricks or killing them when they are in. Most of these methods failed on a national scale partly due to inefficiency and partly to labour and supply difficulties. Staddles are probably one of the oldest means of protecting corn-ricks and appear to have been used extensively in many parts of the country in the past. If properly made, erected, and maintained, they are probably the most effective method used; but, since present conditions of labour and supply would make them difficult to put into general use, no attempt has been made to revive the practice. Other protective methods, such as various types of fencing, are also ruled out for the same reason, and the present agricultural pest control policy emphasizes the importance of destruction of the pests rather than the protection of crops and stores by mechanical means.

The Rats Order, making it an offence to thresh a rick without fencing, to prevent the escape of rats, should have had an important effect on the residual populations left after threshing and hence upon the population available to start future infestations; but much damage occurs if control is left until this stage (Ch. 11). Gassing has so far proved ineffective as a simple means of killing more than a small proportion of the rats in corn-ricks. Trapping with gin traps, although useful in some conditions, requires too much time and skilled labour to be of general application to corn-rick rats.

Poisoning remains the most fruitful method of attack, and an attempt has been made to evolve poisoning methods effective for corn-ricks, which can be easily used by operators and conform with the methods in use on general farm and other rural infestations. For this reason little attention has been paid to evolving perfect baiting and poisoning methods for corn-ricks —which could almost certainly be done—by using more elaborate baits or longer prebaiting periods. The work has been concentrated rather on studying the use on corn-rick populations of the baits found to be effective in other conditions and using them by methods which are reasonably practicable for the type of operators, such as land girls, employed by W.A.E.C. for pest destruction.

Most of the trials quoted below were made on corn-ricks in Oxfordshire and Berkshire with the co-operation of farmers, threshing foremen, and W.A.E.C. officers. The standard procedure adopted was to poison ricks scheduled for immediate threshing, so that the results could be accurately checked by a count of live and dead rats as the rick was threshed. Other trials are included in the Compton Area Control Scheme, on ricks left unthreshed for long periods after poisoning. The general trace evidence of these operational trials has agreed with the results obtained in the controlled tests given below.

(*b*) Methods

The number and type of holes convenient as baiting points vary considerably with different ricks and sites. It is difficult to lay down any standard procedure for baiting corn-ricks other than that every well-used hole in both the rick and the surroundings should be baited. That is the general principle adhered to in these trials; but is not one that can be generally recommended because of the dangers from residues of poison bait (Ch. 2, Appendix 2).

In some ricks, when the majority of the rats live in base holes, effective results can be obtained by baiting at ground level only. In other ricks it is impossible, without using containers or artificial cover, to avoid baiting holes in the body of the rick. In the present trials only the larger side holes were used, well padded, often with a platform of dung. The baits were inserted far enough to be clear of rain or sun but within reach for removal after poisoning.

The average number of bait points used per rick in twenty-eight of the rick sites in Table 1 was twenty-three. A simple isolated rick with a fairly heavy infestation normally takes 20–30 baits. In very large holes, which appear to be used by many rats, two or more spoonfuls of prebait or poison bait are placed, at the discretion of the operator. The ricks in this part of the country are of the larger size, generally taking a full day or longer to thresh.

Most of the baiting of corn-ricks has been with sugar-meal or moist rusk. The percentages of poison in the base have followed those found effective for other work: arsenic, 15% in dry baits; zinc phosphide, 5% in all baits. Zinc phosphide has been used at 2% in rusk in some of these trials, but further work is needed before a change in the percentage is advised; 10% zinc phosphide was used in dry baits in some of the earlier trials with this poison but there is no evidence that it is more effective than 5%.

Several variations in the number and sequence of prebaits were tried, but most of the trials were carried out with the system adopted as standard for rural work: prebaiting on the first and third days, poisoning on the fifth day (generally referred to as the '1-3-5' or '2-gap' system).

As the poisoning of ricks frequently entails baiting a long length of hedgerow or stacks of baled straw, where a number of rats may be living and dying, the numbers of rats found in the rick at threshing may not be the total population poisoned. For the purpose of checking results of poison trials, it is assumed, in such cases, that the rats found in or immediately outside the rick represent a fair sample of the total. When two or more ricks are built close together the results for the group are combined as one trial.

(*c*) Results

The results of a number of trials using arsenic and zinc phosphide are classified in Table 1. The arsenic used in these trials was refined Canadian arsenic and the zinc phosphide was the standard product used in all other work on this poison.

TABLE 1. *Corn-rick poison trials by hole baiting: results at threshing*

*Bait base**	*Type of rick*	*No. of ricks*	*No. of prebaits†*	*No. of bait points*	*Total population*	*% dead*
			(*a*) *15% arsenic*			
Sugar-meal	Wheat	2	2 G	?	36	86·1
,,		3	2	?	42	85·7
,,		1	1	?	27	63·0
,,		2	1	?	35	40·0
,,	Barley	2	2 G	?	57	91·2
,,		3	2 G	?	18	88·9
,,		1	2	?	9	66·7
,,	Oats	9	1 G	?	68	80·9
,,		1	1 G	?	22	81·8
,,		2	1	?	9	33·3
			(*b*) *5% zinc phosphide*			
2:1 rusk	Wheat	2	2 G	20	26	100
1:1 rusk		1	2 G	31	24	79·2
,,		1	2 G	120	> 52	100
,,		4	2 G	32	25	80·0
,,		2	2 G	?	18	88·9
,,		2	2	65	67	86·6
Sugar-meal		2	1 G	30	58	84·5
2:1 rusk	Barley	1	3 G	44	18	94·4
1:1 rusk		1	2 G	23	32	93·8
Sugar-meal		2	2 G	?	23	91·3
,,		2	1 G	?	39	84·6
,,	Oats	1	2 G	40	42	97·6
,,		3	2 G	52	> 17	> 88·2‡
,,		1	2	34	39	100
1:1 rusk		1	2	?	31	100
Sugar-meal	Wheat in barn		2 G	60	*c.* 86	*c.* 81·4
,,	Oats in Dutch barn		2 G	13	*c.* 9	100
			(*c*) *10% zinc phosphide*			
,,	Oats	1	2 G	20	29	93·1
,,	Oats and peas	2	2 G	12	15	100
,,	Linseed	1	2 G	12	6	100
			(*d*) *2% zinc phosphide*			
2:1 rusk	Wheat	1	9	27	49	95·9
,,		4	1 G	?	22	54·5
,,		2	1 G	?	8	75·0
,,		2	0	?	5	80·0
,,	Peas	1	0	20	16	87·5

* Rusk used with 1 or 2 parts by weight of water.

† G = gaps in the prebait system, e.g. 2 G = prebaits 1st and 3rd days, poison 5th day (1-3-5 system).

‡ = threshed a long time after poisoning, number of bodies in rick not accurately checked.

There appears to be no important difference, as suitable baits, between rusk and sugar-meal. Both are taken readily in all normal rural conditions including corn-ricks, and their efficiency as standard bases for both poisons has been amply demonstrated. All the arsenic trials in ricks were carried out with sugar-meal bait, but there is no reason to suppose that arsenic at 10% would not be equally effective in rusk, as it has been found to be in other habitats.

Although there is a good deal of variation in the percentage killed in individual ricks by the same treatment, it is clear that the 1-3-5 system is a very reliable method of obtaining between 80 and 100% kills both with arsenic and zinc phosphide. The average kills by this system for the three types of ricks, combining arsenic and zinc phosphide results, are:

$$\left.\begin{array}{lcc} \text{Wheat} & 5 \text{ trials} & 87\% \\ \text{Barley} & 4 \quad ,, & 92\% \\ \text{Oats} & 1 \quad ,, & 98\% \end{array}\right\} \text{Gross average} = 90\%$$

(Four approximate population counts have been omitted.)

Although only one oat-rick is listed under the 1-3-5 system it will be noticed that good results have been obtained in other oat-ricks after prebaiting without gaps, so that there is no doubt that consistently high kills can be obtained by using the standard system. This is supported by general field experience. Rats in ricks of peas or linseed have also been successfully poisoned.

Statistical analysis

Arsenic. The following analysis was carried out by Leslie. There is a marked significant difference between the results of the ten individual experiments, $\chi^2 = 52{\cdot}24$ and, for 9 degrees of freedom, $P < 0{\cdot}01$. The principal part of this heterogeneity is accounted for by the difference between the systems of prebaiting (Table 2). For comparisons which were possible between (*a*) similar systems of prebaiting in different types of rick, and (*b*) individual tests of similar systems of prebaiting in the same type of rick, the respective total χ^2 were (*a*) 3·249 and (*b*) 3·313, there being 3 degrees of freedom in each case. Neither of these values is significant, and, so far as this series of results go, we may conclude that the same system of prebaiting gave similar results in wheat-, barley-, and oat-ricks, and that the individual

TABLE 2. *Analysis of results with arsenic after different systems of prebaiting*

System of prebaiting	*No. of tests*	*Total No. rats*	*% killed*
2 G	3	111	89·2
2	2	51	82·4
1 G	2	90	81·1
1	3	71	47·9

$\chi^2 = 44{\cdot}67$; $d.f. = 3$; $P < 0{\cdot}01$.

tests of the same system of prebaiting in similar types of rick appeared to give consistent results. In a short series of tests, however, it would be difficult to establish any fine differences between the type of corn-rick; for this a much larger series would be necessary.

Zinc phosphide. In the main analysis of these results only those tests using a 5% concentration of poison were considered, and in addition two incomplete counts and those in the two barns were neglected, there being some doubt as to reliability of the counts of living rats made in the latter cases. Thirteen individual tests thus remained.

There is a significant difference in the percentage of rats killed in the different types of corn-rick, the combined results of all prebait systems are shown in Table 3. No statistically significant differences between the systems of prebaiting could be established in this series. Comparing the different systems employed in the same types of corn-rick $\chi^2 = 3{\cdot}314$ for 5 degrees of freedom, and $P = < 0{\cdot}70, > 0{\cdot}50$. It should be noted, however, that compared with the arsenic tests, a more limited series of prebaiting systems was tested with zinc phosphide, no tests being done with only one prebait and only two tests with one prebait with a gap.

TABLE 3. *Analysis of results with zinc phosphide in different types of corn-rick*

	No. tests	*Total no. of rats*	*% killed*
Wheat	6	218	86·2
Barley	4	112	90·2
Oats	3	82	98·8

$\chi^2 = 10{\cdot}262$; $d.f. = 2$; $P < 0{\cdot}01$.

There were four individual tests of the 2-gap system of prebaiting in wheat-ricks and two in barley-ricks. The total $\chi^2 = 6{\cdot}485$, which for 4 degrees of freedom is a reasonable value, P lying between 0·20 and 0·10. So far as this limited series goes, therefore, the individual tests of the 2-gap system in both wheat- and barley-ricks appear to give consistent results, after allowing for the differential mortality according to the type of rick.

(*d*) Other methods

Before the hole baiting method came into general use for rural trials, various baiting methods were tried on corn-rick rats, mostly by Venables. Some of these were quite successful and may, in special cases, be found useful for practical application. In general, if hole baiting can produce adequate results, it is preferable to baiting in special containers or artificially covered points, since the prebaiting period is shortened and the work is much simplified. There are, however, certain sites where containers or covers for the bait would be useful for poisoning, especially round ricks where pigs or poultry have free access. It is not always easy to insert baits far enough under the base of a rick to avoid the attention of a persistent chicken or duck; poultry are certainly very fond of rusk and are easy to prebait.

The following trials were made, mostly using boards leaning against the base of the rick to form a small tunnel accessible to rats but protecting the bait from poultry. The boards were held firmly in position by sticks stuck into the ground or the side of the rick.

(*a*) Dutch barn stacked with wheat, cattle yard attached. Two treatments given at fortnight's interval in the same way. Prebaited with bread mash under boards for 5 days then poisoned with 10% fine arsenic. When threshed, at least thirty-seven bodies were found, but ninety-six live rats were killed and a considerable residue was left alive on the site. A difficult site, probably failed owing to insufficient points to cover the population.

(*b*) Oat-rick, five boards, prebaited 7 days with bread mash under boards. Poisoned with 10% refined Canadian arsenic. Rick not threshed, but holes and traces indicated a complete kill.

(*c*) Oat-rick. Prebaited 5 days with bread mash under boards. Poisoned with 10% fine arsenic. Results from threshing; sixteen dead rats, none alive. 100% kill.

(*d*) Two bean-ricks. Prebaited 5 days with bread mash under boards placed over a shallow trench cut in the ground round the ricks. Poisoned with 10% fine arsenic. The result, checked by threshing, was 79% kill.

(*e*) Eight old tins, one-pint size, were used on the sides of the rick to supplement the hole baiting points. The tins were firmly anchored by means of a piece of thick wire bent round the tin and twisted to form a spike which was pushed into the side of the rick. The tins were baited with rusk. After 8 days all the tins were in regular use by a large number of rats and the poison bait was readily eaten (35 g.) on the eleventh day. One other trial of this method produced no response from the rats, but it appears worth further investigation owing to the high degree of safety and ease of operation. (These results are included in Table 1.)

No conclusive results have been obtained with P3s or drain pipes as bait containers on corn-rick sites. For practical operation by county staffs, containers would have to be very simple to use and easily portable. The long period of lag is a great objection.

(*e*) Summary and conclusions

The main conclusions to be drawn from these trials is that good, but not always complete kills are certain by using the standard system of two prebaits with gaps and baiting at all available sites. Although 100% kills have been obtained by this method in some ricks, the general trend of the results indicates that more certain results nearing this figure could be expected from extended prebaiting, e.g. three of four prebaits instead of two.

In practice, any extension of the prebaiting period for ricks would cause considerable dislocation of routine, since the two prebait system is now in general use on farms. The normal procedure is for all infestations on the farm to be treated simultaneously; so extra prebaiting for ricks would mean more visits and extra labour and would upset the sequence of work. Unless, therefore, completely conclusive extermination could be assured by longer prebaits it is doubtful if the extra work would be worth while. Experience has shown that even complete clearance of rats from ricks in early winter is almost invariably followed by re-invasion and increase, so that one or more follow-up treatments are needed on long-standing ricks.

All these trials involved baiting in every available hole; but it was later found (Ch. 2, Appendix 2) that some danger might attach to this procedure except in the hands of the most careful operators. The practical value of the present work was therefore more limited than had been hoped. A similar series of experiments is needed with red squill, or with baits placed only in holes at the base of the rick.

5. BLOCK CONTROL

(*a*) Introduction

Since there were bound to be many problems associated with continuous control over a large area which would not be encountered in dealing with individual farms or other rural infestations, we were glad to have the opportunity of studying and organizing a comprehensive scheme of rat control centred on the estate of the A.R.C. at Compton in Berkshire. From the working of this project much useful information was gained to form the basis for advice to county pests officers on block control schemes over large areas. In June 1942 farmers on 11,450 acres of down farm land, including and partly surrounding the A.R.C.'s estate, agreed to allow rat control and recording of it to be done. The actual poison baiting was done by Mr. Blissett, the A.R.C. estate keeper, using a motor-bicycle to get around. Standard methods were used (except that all the ricks were poison baited thoroughly—an important point), and at the end of three years the rat population had been reduced to less than a tenth of the original widely scattered infestations on this area. Rats in ricks gave one of the best indices of this change, since these are usually the last refuges of infestation to remain. The average number of rats per rick in three years before the campaign was 22·0, in 1943–5 only 1·2. The whole operation cost about 2*d*. per acre per year, not counting training, supervision, and research.

The area includes the villages of Compton, Aldworth, and Hampstead Norris. The northern half is typical Berkshire downland, mostly arable at that time, while the southern half below the Compton–Aldworth road is more enclosed and permanently cultivated. The total area comes under the control of fifteen farmers. Some of the farmers own several farms, the total being twenty-seven. As some of the farms have more than one set of buildings there are thirty-four definite 'farm units' associated with buildings: farm steadings, field barns, or cattle yards. Of these thirty-four units twenty were rat-infested in varying degree in 1942 and fourteen were free from rats.

As in most agricultural areas, there were three general types of rat infestation: (*a*) farm premises, barns, and other buildings, which may harbour permanent infestations and act as nuclei for re-invasion by fluid populations from the fields, (*b*) old corn-rick sites and hedge-banks: centres round which the field population moves, (*c*) corn-ricks: providing perfect winter food and cover for the field populations.

The principal crops grown on the Compton area are wheat, barley, and oats. Beans, peas, linseed, and rye are very rarely grown. In 1942 the ricks on the whole area in September were: wheat 90, barley 78, oats 83, peas 1. This does not include the equivalent of about thirty ricks, mostly wheat, threshed at harvest.

(*b*) Methods

The general plan on which work was started in the summer of 1942 was to poison all the infestations which could be found on the area and follow up with other poison treatments where failures or re-infestation had occurred. As sugar-meal was the only convenient bait available and, in combination with zinc phosphide, gave such good results, most of the first treatments were made with this bait. Practically all of these first treatments of infested sites gave very good results and most of the farm premises did not require further treatment for several months. In some cases, however, residual rats were left and recovery was rapid, necessitating second and third treatments at short intervals. As shyness was not understood at that time, some of these second and third treatments were done with the same bait and poison, and difficulties soon appeared.

By the autumn of 1943 work at Oxford, and experience on Compton and other areas, suggested that a safe plan for continuous control was to use a different base and poison in alternate treatments on any one site and leave an interval of about 3 months between treatments. An effort was made, therefore, to get the treatments of the main units on the Compton area into a systematic service routine, alternating rusk and zinc phosphide with sugar-meal and arsenic. Since by this time all these infestations had been reduced to a very low level, very few units required treatments at 3-month intervals, so that in any case shyness was not an important factor, and all treatments during 1944 appeared to give consistently good results.

(*c*) Treatments

It is convenient to classify under three heads the various sites which were poisoned: farm buildings, field sites, and corn-ricks. This distinction is not always a sharp one, however, as some of the field barns owed most of their infestation to the unthreshed corn stored in them and might therefore be regarded as permanent corn-rick sites. Many of the field sites are associated with corn-ricks and the killing of rats on these sites certainly influences the infestation of ricks which may be erected later. In many cases where farm buildings or ricks were infested, rats were found in hedge-banks and other outside points at distances up to about 400 yds. from the main infestation. These were dealt with as part of the building or rick colony although they may have existed quite independently.

(i) *Farm buildings.* Table 4 gives a rough indication of the scale of the work and the relative size of the infestations on the main farm units. The number of dead rats found is not, of course, a reliable index to the population because of the variation in baits and poisons used and the difference in habitat.

TABLE 4. *Scale of operations. No. of treatments on twenty main farm units on the Compton area, June 1942 to May 1945*

1942	*1943*	*1944*	*1945*	*Bait points at first treatment*	*Total bodies found over whole period*
2	2	3	0	45	66
2	4	3	1	26	75
3	5	1	1	50	85
1	2	2	0	62	34
1	2	1	1	30	51
2	2	1	0	92	30
1	2	2	0	36	33
0	3	2	1	120	149
0	2	2	0	84	37
0	3	1	1	32	49
2	1	2	0	15	24
1	0	1	0	9	5
2	1	1	0	28	28
1	1	2	0	24	5
1	2	2	0	44	7
1	1	2	0	40	15
0	3	2	0	212	63
1	0	1	0	35	6
0	4	2	0	60	45
4	1	0	0	29	46

The success or failure of a treatment was judged largely by traces found on examinations of the site at 8–20 days after poisoning. Holes were blocked and runways disturbed 1 or 2 days after poisoning so that fresh traces could be identified fairly easily. There is no doubt that all of the first treatments gave very high kills, comparable with the standard for measured trials where nothing under 85% is regarded as successful. In follow-up treatments on small populations it is, however, more difficult to make a reliable assessment of the success by traces alone, especially where there is abundant cover such as baled or loose straw, stores of sacked corn, wood piles, or dense vegetation.

(ii) *Corn-ricks.* Any corn-rick found to have a rat infestation was poisoned by the normal methods. The general practice in the autumn and early winter, when the first signs of infestation appeared, was to leave the ricks for 2–4 weeks until the holes became suitably established for use as baiting points. Some infestations were not discovered until they were well established—these were treated immediately. Baiting was done in both ground and side holes in the rick. Most of the first treatments of corn-ricks were apparently successful: in some cases confirmed by bodies found at threshing. Some of the ricks remained free from rats for several months afterwards until they were threshed; others became infested again rather quickly (after 4–6 weeks). Second or third treatments were given as required after an interval of 2–4 months, using the normal change of bait and poison (except during the first trial period of 1942–3). The general impression gained with repeated treatments of long-standing ricks was that second and third treatments were not as successful as they are normally on farm units. The total number of treatments of corn-ricks and the number of bodies picked up outside the ricks are given in Table 5.

TABLE 5. *Corn-rick treatments*

	No. of ricks treated	*Treatments*	*Bodies*
June–Sept. 1942	9	9	45
Oct. 1942–Sept. 1943	104	218	458
Oct. 1943–Sept. 1944	92	146	94
Oct. 1944–Jan. 1945	32	32	20

(iii) *Field sites.* All the infestations found in field banks, hedgerows, &c., on the Compton area were either of a temporary seasonal nature or associated with rat colonies in corn-ricks or farm units. There were no hedge-bank populations which could be said to be permanent, living in the banks all through the year and feeding entirely on the field crops. When field colonies were treated they were normally cleaned up with one treatment. It seems probable, however, that many temporary field colonies (or family units) were not found during the summer months, because of the heavy cover of vegetation. These scattered field colonies probably form the main reservoir from which infestation of corn-ricks and farm units occurs in the autumn and winter.

On several localities there was a noticeable infestation of hedge-banks during the autumn: usually during October and November, not before or immediately after harvest. The roadside banks between two farms on the A.R.C. estate form a good example of this. Each year, in October or November, a number of rats appeared 'spontaneously' in these banks, which had been rat-free all through the summer months. This invasion is shown clearly in the difference between the census baiting figures for August 1944 (0 g.) and November (500 g.). Some details about poison treatments on this site are given in Table 6. There were no other infestations of these banks during the whole period, although corn-ricks in the vicinity became infested during the winter months.

TABLE 6. *Hedge-bank treatments*

6 Nov. 1942	39 baits sugar-meal and zinc phosphide		Bodies picked up	15
21 Oct. 1943	48 ,, rusk	,, ,,	,, ,,	10
29 Nov. 1944	28 ,, sugar-meal	,, ,,	,, ,,	8

Throughout the area it was obvious that a scattered field population moved into the corn-ricks and farm units during the late autumn and early winter, some rats going first into temporary quarters in the field-banks, others going direct to the ricks and farms. There is very little evidence on the range of such movements: they are probably very variable, depending on the accessibility of suitable winter sites from the rats' summer habitat. Table 7 gives the total number of field treatments, with zinc phosphide in all cases. Since approximately the same amount of inspection and searching for these field populations took place each year (least in 1942), these figures probably reflect the influence of the campaign as a whole upon the elusive field reservoir, if we assume that this population was derived from the breeding of rats which survived the winter and spring poisonings of farm units and corn-ricks.

TABLE 7. *Field treatments*

	Sites treated	*Approximate no. of baits*	*Dead rats found*
1942	22	340	58
1943	19	190	41
1944	7	86	19

(*d*) Discussion

(i) *Populations.* Although it is obvious that the rat population of the whole Compton area had been reduced to a small fraction of its former dimensions and the poisoning campaign could be regarded as successful, it is not easy to express the general result in figures. Census work for each operation was not carried out, as with normal scientific trials, through lack of time and manpower.

The figures for rats killed at threshing of corn-ricks give a good index of the general reduction in numbers on the area. For the A.R.C. estate detailed figures are available since 1939 (Table 8). The average total of rats killed in ricks for the three seasons before the campaign started was 703, compared with 46 in 1944–5, a reduction of 93%. It will be seen that the number of ricks from 1942 to 1945 was greater than for 1939–41, due to war-time increases in corn growing. It might be argued that this increase in the number of ricks would make it probable that a higher proportion of the total population of the area would be found in ricks in 1942–5 than in previous years, making the true figure for total reduction rather higher than 93%. On the other hand, the increased number of ricks does not mean a corresponding increase of new rick sites evenly distributed over the area, as many of the extra ricks were grouped on the normal sites used in previous years. The average figure for rats per rick for the first three years is 22·0 compared with 1·2 in 1943–4 and 1944–5, showing about 95% reduction. It is reasonable to assume that the true figure lies between these two since the increase in ricks might lower the first and raise the second percentage. These figures are worth comparing with the National Survey averages for ricks (Ch. 11) during the first 3 months of 1943:

TABLE 8. *Agricultural Research Council Estate, Compton. Active* rats found in ricks at threshing; years beginning 1 October*

	1939–40	*1940–1*	*1941–2*	*1942–3*	*1943–4*	*1944–5*
Total ricks	29	31	36	46	61	40
Infested ricks	25	23	24	14	18	11
Total rats	770	513	826	159	76	46
Average rats per rick (all)	26·6	16·6	22·9	3·5	1·2	1·2
Average rats per infested rick	30·8	22·4	34·4	11·4	4·2	4·2
% ricks infested	86	74	67	31	30	27

* 'Active' rats means all live rats in the rick, excluding young still confined to the nests.

% ricks infested = 67·8
Rats per infested rick = 10·3
Rats per rick (all ricks) = 7·0

For the whole area, records are not available before the start of this campaign, although it is well known that very large numbers of rats were found in corn-ricks at threshing: probably the A.R.C. estate figures represent a random sample of the condition of the whole area. In Table 9 the figures for two threshing seasons after the campaign started show clearly that a low level of rick infestation was obtained over the whole area similar to that on the A.R.C. estate. Actually the figure for the farms outside the A.R.C. is lower in 1943–4, being 0·8 compared with 1·2 rats per rick. Table 9 does not include all the ricks on the area outside the A.R.C. estate, but about 70% of the total. For the remainder, records were not obtained owing to the usual difficulties associated with threshing operations. It is, however, quite certain that any rick containing a noticeable number of rats would have been recorded and it is probable that most of the ricks for which records are missing had no rats, so the average given may be slightly higher than the true figure.

TABLE 9. *Active rats found in corn-ricks at threshing, years beginning 1 October, including all available records for Compton area*

	Wheat		*Barley*		*Oats*		*Various*		*Total*		*Average rats per rick*
	Ricks	*Rats*	*Ricks*	*Rats*	*Ricks*	*Rats*	*Ricks*	*Rats*	*Ricks*	*Rats*	
1942–3 .	72	305	56	152	70	36	3	4	201	497	2·5
1943–4 .	75	80	49	59	63	23	12	15	199	184	0·9
Totals .	147	385	105	211	133	59	15	19	400	681	. .
Average rats per rick (all)	2·6		2·0		0·4		1·3		. .		. .

The figures in Table 5 also support the general conclusion of reduction in corn-rick infestation with the progress of the campaign. In the 12 months ending September 1944 the number of ricks infested was lower than in the previous year (although more ricks had been built) and the much smaller number of bodies found indicates the general low level of numbers in these ricks.

A further indication of the reduction in numbers on the farm building units can be obtained from the total numbers of bodies found after poison treatments (Table 10), although the use of both zinc phosphide and arsenic and the general unreliability of bodies as an index make it impossible to base accurate conclusions on such figures. A large farm on the edge of the area was not taken into the scheme until August 1943, and rats picked up there have been given separately below. Incidentally, this farm provides evidence of the continuance of heavy infestation on untreated land on the margin of the area.

TABLE 10. *Corpses recovered from buildings in the Compton area*

June 1942–May 1943	450
June 1943–May 1944	167 (+113 see text)
June 1944–May 1945	87 (+ 36 „)

In the autumn of 1944 an attempt was made to get a census of the residual population on the A.R.C. estate by the surplus baiting method. It was impossible to set out containers (pipes) to cover the whole area completely; so a careful search was made and pipes were established at every point where rat traces could be found or where previous experience suggested that rats might be expected to appear during the period after harvest. Twenty-one pipes were placed, baited with wheat, on 21 July 1944 and measurements made at intervals of a few days up to 14 August. The pipes were left in position and re-baited on 24 October and a further series of measurements was made during the period up to 8 November. The average takes during the last three measurements in each of these periods were 415 and 1,140 g. wheat respectively.

Apart from the general low infestation shown by this census baiting (equivalent to 45 rats in November), the difference between the August and November figures is interesting as it shows the autumn invasion of rats from the fields. Moreover one of these areas (take 290 g.) had been successfully poisoned immediately after the August census.

Evidence of continuing heavy infestation outside the Compton area would form useful support for the success of the Compton scheme. This is not easy to obtain simply because some of the big estates took an active interest in the Compton methods and also carried out large-scale poisoning. However, the following data give some indication that the Compton results were not due to any widespread natural mortality after 1942.

(*a*) From 10 to 30 March 1943 the keepers on a neighbouring estate carried out poisoning over about 5,000 acres (including farm buildings, corn-ricks, and banks) adjoining the Compton area on the north-west. Sugar-meal prebaiting and zinc phosphide poisoning were used on similar lines to the Compton work. 965 dead rats were picked up after this treatment, which took 8 lb. zinc phosphide.

(*b*) There were sixty-three rats in two nearby oat-ricks in October 1944.

(*c*) In June 1944 there were about 34, 81, 86, and 148 rats on four farm units outside the area (Ch. 4, Table 51 (*d*), last four tests).

(*d*) A further indication of the extent of rat infestation on the surrounding area is given by the numbers of rats picked up by the Compton operators after poisoning with zinc phosphide on farms outside the area (Table 11).

TABLE 11. *Corpses recovered during nine treatments outside the area*

Dec. 1942	42, 143	
Jan. 1943	67	
July 1943	75	
Nov. 1943	60	
Jan. 1943	114, 32, 80	Outside ricks
Mar. 1943	34	

(ii) *Labour and materials.* An exact statement of labour costs in the Compton scheme is impossible as the operator was not employed solely on rat control but spent much of his time on other estate work and rabbit control. An estimate based on the total number of poison treatments, with a generous allowance for inspections gives a total of 2,550 man-hours spread over three years, which is about 40% of the man's working time.

From the figures in Table 12 and experience of the working of the scheme we could reasonably expect one man, working full time, to cover efficiently at least twice the acreage of the Compton area—say 25,000 acres of similar country, at a cost of between 2*d*. and 3*d*. per acre. These figures show a much lower cost per acre than the normal charges for rat control done by the W.A.E.C. (average about 6*d.* per acre), but it must be pointed out that most of the Compton area is made up of big farms with relatively few buildings and large fields without general heavy infestations of hedgebanks. A similar acreage, e.g. in parts of South Wales or Lancashire, might include 150-200 small farm units, taking much more time in treatments and inspections. The transport costs were also comparatively low at Compton as the operator lived near the centre of the area. No charge is put against supervision and administration, which is usually rather heavy in a government organization.

TABLE 12. *Costs based on prices in 1946*

(*a*) *Materials*	£	*s.*	*d.*
540 lb. flour	5	0	0
280 lb. sausage-rusk	5	12	0
62 lb. sugar	1	11	0
16 lb. zinc phosphide	3	4	0
13 lb. arsenic		16	0
	16	3	0

(*b*) *Total*	£	*s.*	*d.*
Labour, at £4 per week	250	0	0
Materials	16	0	0
Travel (motor cycle)	40	0	0
	306	0	0
Cost per annum	102	0	0
Cost per acre per annum			2·14*d.*

It is clear, however, that efficient rat control could be established on a group of 40-50 farms in this type of country by employing one good operator on an area of between 20 and 30 thousand acres, for a co-operative contribution of 3*d.* or 4*d.* per acre. Thirty shillings for a hundred-acre farm, or £15 for a thousand acres, is a very reasonable price for such a service, and with a block of 25,000 acres this would yield £375—ample to cover the wages, materials, and transport of an experienced operator. In an area with more and smaller farm units, where the total workable acreage might be halved, it should still be possible to raise sufficient revenue by making a minimum contribution of about 30*s.* per farm for all under 100 acres. If the services supplied by county W.A.E.C. have to be curtailed in the future there seems every reason to encourage co-operative rat control schemes of this kind.

(iii) *Rat-free farm units.* Of the thirty-four 'farm units', fourteen were practically free from rats in 1942 and remained so throughout the next three years. In many of these cases there is little doubt that cats were the important factor. On the other hand, several farms with numerous cats had normal rat infestations and required repeated poison treatments. On about half of the fourteen rat-free units cats could account for the absence of rats. With one possible exception (with one cat), most of the units on the Compton area which had regular food supplies and few or no cats, were rat-infested. It is probable, however, that the poisoning campaign over the whole area considerably reduced the rat pressure on the free farms, so we cannot be sure that the continued freedom of some of the farms was due to cats alone. Other ecological factors which are little understood influence the rats' reaction to and choice of different habitats and may be more important than the presence of cats. The effect of introducing cats on to some of the A.R.C. farms after the rats had been reduced by poisoning or other methods has been analysed by Elton. He found that satisfactory conditions were maintained in places which had formerly been overrun with rats.

(iv) *Maintenance.* After a large area has been systematically poisoned for one, two, or three years the rat population should, as at Compton, be well below nuisance level, but not completely exterminated. There is no reason to doubt that, where no further action is taken, rats will eventually reach high numbers again. A most important problem, therefore, is to find the most economical method of keeping the rats below a density at which they can cause serious damage. Actually most of the work during 1944–5 at Compton consisted of this maintenance, at the same time attempting to drive down the density to the lowest possible level. This meant finding small infestations and re-invasions and carefully carrying through a poison routine for perhaps less than a dozen rats spread over a farm unit.

By keeping a man employed on an area of, say, 20–30,000 acres for this purpose there is no doubt that the job should be done efficiently and the expenditure might be justified. Most of the work is inspection of sites and tracing rats, involving many negative surveys and few chances of doing a job which shows results. In practice it is extremely difficult for an operator in such a rural area to keep up sufficient enthusiasm to do this sort of maintenance conscientiously and efficiently as a full-time job. The work itself becomes uneventful and boring, creating indifference, and the operator is subjected to much sarcasm from farm workers who regard the phenomenon of an able-bodied man looking for non-existent rats as a waste of time and money—which does in fact have a most discouraging cumulative effect on the operator and he can easily adopt the same attitude towards his own job.

It is suggested that a better system of maintenance after a campaign of this type would be for one farm worker on each farm to be responsible for poisoning any rats which appear. This might be done by a complete survey, and treatment of all infested sites about November and April each year, or by treatments when and where rats are noticed. The former system might be expected to work best on a large farm of 1,000 acres or more, but on the smaller farms there should be no difficulty in getting information to the operator immediately rats appear on any part of the farm. Providing two bases and poisons are available and the operator is instructed in methods, and warned against shyness in rats, such a maintenance should prove quite cheap, easy, and effective.

On estates where game is preserved and a keeper is responsible for vermin control on several farms, there is every reason for using him to keep rats down on all sites and at all seasons on the farms. Since he should in any case poison rats for the protection of game-birds, his work should cover the farmers' interests as well.

The fencing of ricks at threshing and killing of these rats is certainly an important factor in control and, like other methods when density is low, it is very easily neglected by threshing contractors and farm workers. If, from the appearance of the rick, it is judged that there are 'practically no' rats in it, there is a marked tendency to omit the fence at threshing—an omission which soon becomes a habit.

The problem of maintaining control when the rat population has been reduced to a low level is now a general one, resulting from the activities of the county rat destruction services. Pests officers are finding it increasingly difficult to justify the expense of inspection, travelling, and treatment in these conditions. It is suggested, therefore, that when maintenance is planned by county authorities the organization and staff required might be considerably reduced if groups of farms could be persuaded to provide their own labour. A district supervisor or local authority might find it convenient to organize such groups, training the part-time farm operators and supplying them with bait and poison. The cost would be less to the farmer than the normal service and the operating staff employed by the local authority could be reduced to deal only with areas where the farmers did not wish to carry out the work or could not be trusted to do so. This system would naturally require full trial under careful observation before being advocated for general application and might be impracticable in areas with large numbers of small farms and few farm employees. It is suggested only for consideration when the economic planning of future rat control is under discussion.

(*e*) Summary

1. This section describes the working and results of a rat control scheme covering an area of about 11,450 acres of agricultural land in Berkshire, including the A.R.C.'s experimental estate at Compton, over a period of about three years.

2. The work was carried out by a local operator, using systematic poisoning after prebaiting on the 1-3-5 day system. Rats in corn-ricks were poisoned by baiting in all available holes; this method however is not safe enough to be recommended universally.

3. The results, as shown by the relative numbers of live rats found in corn-ricks, supported by other evidence, indicate a general reduction of the rat population by over 90%, to a level at which damage ceased to be noticeable.

4. The cost of the operation averaged over three years, including labour, materials, and transport but not supervision, was about 2*d.* per acre per annum. Such low costs could not, however, be anticipated in a more enclosed area with larger numbers of smaller farm units.

5. A maintenance service is necessary to keep the rat infestation from building up again in local units. This appears to be mainly due to the difficulty

of eliminating the scattered summer breeding population in the field. Methods for carrying on an economical maintenance service are suggested.

6. ORGANIZATION OF RURAL RAT CONTROL

In 1939 there was practically no government organization of rat control in rural areas. The M.A.F. employed one technical officer whose main duty was to advise on pest destruction, but he had no staff and no authority to carry out rat destruction. A publicity campaign for a special 'rat week' in November each year was about the sum total of the official rat control. All the county councils had been given powers under the Rats and Mice Act of 1919 to take action against rats on any premises after the occupier had failed to comply with their Order. Some of the counties delegated these powers to the rural district councils while others retained them. In either case very little use was made of the 1919 Act, since its execution necessitated the employment of official rat-catchers by the county or rural district, which was regarded as an impossible burden on the local ratepayers. Before the outbreak of war only seven county councils employed rat-catchers or 'rodent officers' and these men had little, if any, assistance in the work of rat-catching.

The formation of the County W.A.E.C. in 1939 opened a completely new field for pest control, since any officers or labour employed did not incur a risk of loss to the ratepapers, but such losses were covered by the central government. Although money spent on control was supposed to be recovered from the occupier of the land, strict balancing of expenditure and revenue was not insisted upon by many committees.

The W.A.E.C. were a temporary organization whose primary function was to speed up agricultural production. Their powers were all under the Defence Regulations and had no effect upon the powers already possessed by county councils, such as the 1919 Act. In practice this somewhat ambiguous condition of two different authorities having similar powers within the same county caused very little confusion. The agricultural committees of the county councils were automatically disbanded since most of their members and staff were seconded to the new W.A.E.C. and the counties, having done nothing with the 1919 Act since its inception, were content to be relieved of their responsibility for rural areas.

An administrative mistake in the early days of the W.A.E.C. was responsible for considerable handicaps in the development of rat control during the war. One of the first Orders made by the Minister of Agriculture under the Defence Regulations was the Rabbits Order (1939) giving the committees powers over rabbit destruction. The Ministry stressed the urgency of dealing with the rabbit pest and persuaded most of the counties to appoint 'rabbit officers' immediately. It was not until 8 or 9 months later that the first mention of rat control reached the committees, in the Rats Order (1940). Meanwhile the rabbit officers had become firmly entrenched and were getting on with their jobs. The logical step for most committees to take was to place rat control under the rabbit officer. Since the men appointed as rabbit officers were chosen for that one function only (they varied from baronets to ex-poachers) it follows that many of them had little interest in, or knowledge of, rat control. Many of these men were quite efficient at carrying out or supervising rabbit control, but could not be expected to build up a progressive organization for farm pest control over a whole county. Throughout 1940 and 1941, therefore, many counties did very little to create an effective rat control staff. In fact by the end of 1941 several county 'pests officers' were merely rabbit-catchers with one or two assistant trappers, in spite of a frequent issue of urgent memoranda from the Ministry to the committees. Since the powers given by the Rats and Rabbits Orders were delegated by the M.A.F. to the county committees, the Ministry officials were unable to control or plan, except in an advisory capacity, a rat campaign on a national scale. The Ministry's central pest control staff consisted of a technical adviser with (eventually) four assistants, responsible to a civil servant who had many other matters to deal with. There is no doubt that a better development of rodent control might have been achieved—by the right people—if the whole project had been departmentalized under one head from the start and the central staff given more authority to organize and direct the work of the committee staffs. Such an arrangement came into force soon after the end of the war and certainly gives a better administrative framework on which to build an efficient system of rodent control.

In Scotland the Board of Agriculture did not delegate its rat control powers to the county committees. The Board maintained its own staff who operated in any part of Scotland, in co-operation with the committees but technically independent of them. This also proved to be rather an inefficient method, since it tended to concentrate effort into a few selected areas, and lacked the detailed local knowledge and personal approach of the committee pests officer.

In spite of these faults in administration and organization, however, most of the counties did build up active rat control departments. From 1942 to 1945 rats gradually took first place in the work of all the county pests departments and by the end of the war the Ministry found it necessary to admonish many of the committees for neglecting rabbits and devoting all their energies to rats.

As each county was given a fairly free hand in developing its own rat control there were naturally many different types of organization built up to deal with the problem, partly dependent upon the tradition of rat control in the county, availability of suitable labour or the personal views and experience of the pests officer concerned. In all counties, however, the policy of persuasion rather than force was adhered to in dealing with farm rats. The committees had ample powers to enforce rat control and many other things on farmers but these powers were rarely used until it was proved that co-operation was impossible. The Rats Order makes it quite clear that the responsibility for killing rats rests with the occupier of land and the obvious action to be taken by the committees is to tell him to kill the rats, with the threat that if he does not do so the committee will do it for him and make him pay for it. It soon became obvious that this policy would not work. Very few farmers, or their employees, have the specialized knowledge necessary for effective rat control and, in the intensive war-time production drive, had very little time to devote to it. It was clear that, as well as creating personal friction with the farmers, the committees would be forced to keep a large staff of operators to clear up where occupiers had failed to kill their rats, and the work of repeated surveys and inspections by the committee would involve as much labour as the actual operation. Therefore practically all counties, with the support and advice of the Ministry, set up a staff of rat-killers and contracted with the farmers to carry out the job of rat control for them, in return for a fee calculated to cover all or most of the operating costs but not the organizing and administrative costs. The committee thus became the servant of the farmer, but with the mutual knowledge that authority could be exercised if the farmer refused the service.

The type of contract between the farmer and the committee, the fees charged, and the service given all varied considerably in the different counties during the early days of this work, but they have gradually become more or less standardized. Most counties now charge the farmers a fee based on the acreage of their land, and this averages about 1*s*. per acre for a year's service. The service normally consists of three or four poison treatments during the year, if necessary, with occasional gassing or trapping in very difficult infestations. Special prices are usually quoted for premises such as mills, knackers' yards, refuse tips, &c., in rural areas.

The organization of pest control in Gloucestershire may be quoted as one example, not unfortunately typical, of how efficient practical operations were conducted. A few counties, such as Norfolk, had more staff, but most counties had less. At its war-time peak the rural service in Gloucestershire employed the following:

Chief Pests Officer (Mr. J. C. Brocklebank)

5 inspectors for rats
30 rat-poisoners
4 inspectors for rabbits
1 inspector for grey squirrels
15 rabbit-trappers
Office staff of 5 girls

Approximately 600 contracts for rat destruction were in operation, many of which included several individual farms or sets of premises. All of the buildings, corn-ricks, and other sites on the areas covered by these were inspected and, if necessary, serviced about six times during the year, but the average number of actual treatments on each farm per year was about four. Practically all the staff, including the operators, was mobile, using either small vans provided by the committee or their own cars. The revenue from the contracts was adjusted to cover the whole of the actual operating costs including baits, poisons, traps, and the wages and transport of the operators. The salaries and expenses of the pests officer, office staff, and inspectors were borne by government funds. The average cost per annum to the farmer on this basis worked out at about 1*s.* per acre, although each contract was the subject of a special quotation based on the pests officers' estimate of costs, rather than on a flat rate for acreage.

Norfolk adopted a rather different form of contract, charging a flat rate per 100 acres (at first 17*s.* 6*d.*, but later increased) for one poison treatment after prebaiting, irrespective of the size of the farm or degree of rat infestation. Normally farmers were persuaded to take two treatments a year, in the spring and autumn. At one time the committee were carrying out rat contracts covering over 400,000 acres of farm land in the country.

Throughout the war the method advised by the M.A.F. (as a result of research by the Bureau) for farm poison treatments was hole baiting with two prebaits. Although many counties did not at first pay much attention to this advice, and allowed pests officers and operators to do as they thought best, this method was eventually adopted as a standard practice. Similar difficulties were encountered in the early days in standardizing the recommended baits and poisons: sugar-meal or rusk with zinc phosphide, arsenic, or red squill.

The normal procedure for committee staff when arranging these contracts was for an inspector to visit the farm, make a brief inspection of the buildings and try to persuade the farmer to sign a contract. On the rare occasions when the farmer would not agree to a contract, and persisted in harbouring a heavy infestation, the committee would serve an Order upon him. In the Order he would be given 14 to 21 days to clear the rats to the committee's satisfaction, but in such cases he would rarely take any effective action, so the committee staff would carry out the work at the expiration of the Order and send him an account for it. As the committees normally paid out considerable sums of money to most farmers for cultivation, grants, subsidies, &c., a recalcitrant debtor was easily dealt with by deducting his debt from amounts due to him for other purposes. Since any money spend on rat-killing was a legitimate farm maintenance charge and was subject to rebate on income tax, the net cost to the majority of farmers —especially the larger ones—was very small.

After the inspection and signing of the contract the first poison treatment would normally be carried out as soon as possible by the operator or operators working in that area. This would entail at least three visits to the farm, for prebaiting and poisoning. Most counties preferred to send an operator on the day after poisoning to clear up dead rats and any poison bait left exposed in a position dangerous to farm stock. Others contended that if the poison was laid with due care to begin with there should be no need for this fourth visit, which considerably increases the labour and travelling costs. The risk naturally depends a great deal on the skill, forethought, and experience of the operator. There have certainly been a good number of deaths among cats and poultry and an occasional one among other stock, but in view of the large number of farm treatments carried out with powerful poisons during the war years the number of casualties to farm stock was surprisingly low.

Some of the better organized counties, such as Gloucestershire and Norfolk, found that more economical working was obtained by sending operators out singly than by gangs of two, three, or more, in spite of the extra transport costs involved. One good man, working on a carefully planned programme to avoid waste of travel time, can bait at least three and often four sets of farm buildings with a few outlying corn-ricks in a day, but in actual practice it is doubtful whether the average turnover exceeds two farm buildings per day per man, or four completed treatments per week. Many of the operators interspersed trapping and gassing on certain sites with poison treatments, so they were rarely working to a planned schedule for a considerable period.

There is no doubt that rat-poisoning is an occupation more suited to men than women and the most consistently effective results have been obtained by experienced men. Nevertheless, large numbers of women, mostly from the Women's Land Army, did a great deal of the county rat-poisoning during the war. It is difficult to compare their efficiency with that of the average man employed on this work, as most of the men were chosen individually with some suitable qualifications for the work, whereas many land girls were seconded to it after being trained for normal farm work. After a suitable training period the more interested girls proved quite as efficient as the men at routine prebaiting and poisoning on farms. One disadvantage in the W.L.A. routine was that many of the girls lived in communal hostels and were taken out each day in truckloads, instead of being allowed to work individually from strategic points. Rat-poisoning is not one of the jobs to which any form of gang labour is suited. It requires the steady and quiet concentration and sense of responsibility that one usually finds only in an individual worker.

One of the points about poisoning which proved most difficult to impress upon county staffs was the vital importance of base- and poison-shyness and the use of a careful sequence of baits and poisons to avoid this. Time after time, operators would find a few rats left on a farm a week or so after a treatment with, say, zinc phosphide in rusk. Instead of trapping, gassing, or leaving these for a complete re-treatment, probably with arsenic in sugar-meal, the operator, in passing, would put down a little more zinc phosphide in rusk, quite often without prebaiting. This form of treatment, even on a small scale, naturally gave rise to some very shy residues on farms. Some of the pests officers frankly admitted, about 1945, that the only way they could kill rats on some of their farms was by trapping, obviously because of frequent poison treatments with no planned sequence.

We have, perhaps, emphasized the difficulties of rat control in rural areas and the many faults in administration and organization. But it is through experience of these difficulties and faults that an efficient organization is gradually being built up. There is no doubt that the county units are now carrying out more effective control than we have ever experienced before, and by more careful attention to the principles of rat-poisoning they can continue to improve this service.

7. SUMMARY

1. Before the Second World War there was little organized rat control, though a number of experienced poisoners operated locally. Several large infestations studied in 1939–40 were fairly typical of the legacy of the pre-war years.

2. The rural environment is very diverse, the main habitats being farm buildings, corn-ricks, sites after threshing, hedge-banks, and fields, root stores, and rubbish dumps.

3. Prebaiting for 2 days and poisoning in the holes, with gaps between each baiting, was found to be an efficient and practical means of control. This is known as the 1-3-5 (day) system of hole baiting.

4. Infestations in ricks of all types were also controlled by this means; but there is some danger to human beings from residues of poison bait. Consequently this environment, one of the most vital in the whole rural complex, remains an outstanding practical problem (Ch. 2, Appendix 2).

5. Block control of rats on an area of 11,450 acres was found to be practical and economic. Rats were reduced below the level at which appreciable damage occurred.

6. Large organizations were needed in each county to deal efficiently with rural rat control and many practical problems arose from the rapid expansion of effort under war conditions.

REFERENCES

Ministry of Agriculture & Fisheries (1945). 'Rat control on farms.' 12 pp. St. Annes.

Venables, L. S. V., & Leslie, P. H. (1942). 'The rat and mouse populations of corn ricks.' J. Anim. Ecol. 11: 44–68.

APPENDIX

BAITS FOR RURAL RAT CONTROL

PREBAITS

Two standard prebaits fulfil all normal requirements for rural rat control:

(1) Sugar-meal. Ordinary 'National' flour with 10% by weight of castor sugar.
(2) Sausage-rusk. Dry rusk used for sausage filling in war-time—similar to 'biscuit meal' used for poultry—with an equal weight of water. This makes a moist crumbly bait, very simple to mix and easy to use. 'Medium' grade used for ordinary sausages is the best.

These two prebaits can be mixed simply by volume measures without weighing:

Sugar-meal: 15 parts flour to 1 part sugar.
Sausage-rusk: 2 parts dry rusk to 1 part water. (Add the dry rusk to the water to mix.)

POISON BAITS

To prepare the poison baits, thoroughly mix the correct proportion of poison with the same type of bait which has been used for prebaiting.

The correct proportions of poisons to put in the various mixtures are as follows:

(1) Zinc phosphide–sausage-rusk: 5% of poison by weight in the total wet weight of the bait, e.g. dry rusk 3 lb., zinc phosphide 5 oz., water 3 lb. Should be used the same day as mixed.
(2) Zinc phosphide–sugar-meal: 5% of poison by weight, e.g. sugar-meal 6 lb., zinc phosphide 5 oz. Can be mixed and stored for at least a week.
(3) Arsenic–sausage-rusk: 10% poison in total wet weight of rusk, e.g. dry rusk 3 lb., arsenic 11 oz., water 3 lb. Should be used the same day as mixed.
(4) Arsenic sugar-meal: 15% of poison by weight, e.g. sugar-meal 5½ lb., arsenic 1 lb. Can be mixed and stored for at least a week.
(5) Red squill powder–sausage-rusk: 10% in total wet weight, e.g. dry rusk 3 lb., squill powder 11 oz., water 3 lb. Should be used the same day as mixed.

For sausage-rusk baits the poison must be mixed first in the dry rusk and the whole thoroughly mixed while adding it to the water.

Poison mixing is much simplified if volume measures are used instead of weights. This can be done by making small, graduated tin measures holding the exact weight of poison for a fixed volume of dry bait—1 or 2 quarts, for example—based on the above percentages.

II

A SAMPLE CENSUS OF RATS AND HOUSE MICE IN ENGLISH CORN-RICKS IN JANUARY TO JULY 1943-7

By CHARLES ELTON *and* E. M. O. LAURIE

1. INTRODUCTION

THIS sample census of rats (*Rattus norvegicus*) and house mice (*Mus musculus*) in corn-ricks was begun in January 1943 by C. Elton, who planned and organized the inquiry with the help of A. D. Middleton and L. S. V. Venables. The inquiry was conducted by Elton in 1943 and 1944 (with the assistance of Miss C. Fox in 1944), and continued by Miss Laurie in 1945-7. It was originally designed to find out (*a*) how far rodent infestation of ricks was of general occurrence throughout England, (*b*) how far the results already obtained for the Oxford region were typical of the country as a whole, both in scale and in seasonal trends, and (*c*) whether such censuses would provide a reliable base-line, not only for measuring future trends of corn-rick rat and mouse populations but also of the effects of the National rat-poisoning campaign as a whole upon rural rat populations.

Venables had found that infestation of corn-ricks in the Oxford region during the first two seasons of the war, 1939-40 and 1940-41, both by rats and house mice, was widespread and serious, and the results were later published by Venables and Leslie (1942). On the assumption that such infestations were probably general throughout the country the Government issued 'The Rats Order (No. 2), 1940' and 'The Rats Order, 1941', by which responsibility was allocated for putting wire-netting (or similar fencing, Plate 2) round ricks at threshing time, and killing any rats present. These Orders only applied to England and Wales, though similar Orders have been issued in a large number of counties in Scotland. This method of killing rats, where done effectively, offered opportunities for making good censuses of the rats in ricks. House mice are not killed at all completely at threshing, and are much less easy to count, so that only rough estimates can be obtained.

2. METHODS OF SURVEY

The records were obtained from threshing-tackle foremen in a number of counties throughout the county (Table 1). In order to ensure the highest possible reliability of the observations (which could not be obtained on such a large scale by any other means), a resident in each county, well-known personally to the organizers, was asked to enlist the help of one or two reliable threshing-tackle foremen, preferably not working in adjacent areas.

In some cases recourse was had to the advice of the local pests officer, the threshing officer, and the owners of threshing companies. Each man was provided with a small writing pad on the inside cover of which were typed the questions to be answered. Except for the very small ricks in Northumberland, one sheet was used for each rick threshed (a Dutch barn, Plate 5(*a*), being counted as one rick), and the answers were posted to the Bureau every week or so, so that any deviations from standard recording could be checked at once. The men were given a small payment (5*s.* per month); but their participation in the survey was mainly influenced by their interest in helping a war-time project, all of them being well aware from daily experience of the extent of rodent infestation in ricks. To all the people who have helped in the inquiry, and particularly to these threshing-tackle foremen, we are deeply indebted.

The following questions were answered: (1) County and nearest village or town, (2) Date of threshing, (3) Kind of corn, &c., (4) Number of rats (counting all live rats except helpless nestlings), (5) Whether mice present, (6) Whether over fifty mice, (7) Whether the rick had been poisoned that season, (8) Whether the rick was in the field or in a rickyard (Plates 5, 6), and (9) Foreman's initials. Question (8) was only added to the list in 1947. All records thus obtained were entered in books which are deposited in the Bureau of Animal Population.

The counties sampled are fairly representative of the greater part of England, but Northumberland is the only one north of Lincolnshire. Some records were also obtained from Midlothian, Selkirkshire, and Wigtownshire in Scotland. However, these Scottish samples are too small to be used satisfactorily in comparison with the rest and so have not been dealt with in this account. The total number of counties sampled in England was eighteen and the total number of areas thirty-five, the original aim having been to obtain two recorders for each county. The actual number of recorders however varied from eighteen to twenty-six in any one year (Table 1); but after the increase in the number of recorders in the second year of the inquiry it was endeavoured in the succeeding years to carry it out with the same men, in order to reduce personal differences which might occur in the recording. There is no reason to suspect that the four new recorders for 1947 have introduced any particular bias into the results for that year, as their records are within the normal range.

The inquiry began on 1 January in each year and continued until the end of the threshing season, which varied in the different counties from about April to June. A few records were occasionally received for July and August. As records were nearly always received from all areas for the whole of the first 3 months of the year, the analysis of the figures is mainly concerned with the results from January to March.

One consideration must be mentioned, which underlies the whole interpretation of sample records of rat and mouse populations obtained in this

TABLE 1. *Counties and areas in England from which records of rat and mouse populations in corn-ricks were obtained from 1943–7. The records from each area were obtained by different men*

No.	*County*	*Area*	*1943*	*1944*	*1945*	*1946*	*1947*
1	Buckinghamshire	A	×	×	×	×	×
	,,	B	×				
	,,	C		×	×	×	
	,,	D					×
	,,	E					×
2	Cambridgeshire	A	×	×	×		
	,,	B					×
	,,	C					×
3	Cheshire	A	×	×			
	,,	B	×	×	×	×	×
4	Devon	A	×	×	×		
	,,	B	×	×	×	×	
5/6	Essex–Hertfordshire	A	×	×	×	×	×
7	Gloucestershire	A	×				
8	Hampshire	A	×	×	×	×	×
	,,	B	×	×	×	×	×
9/10	Lincolnshire–Rutland	A		×	×	×	×
	Lincolnshire	B		×			
	,,	C		×	×	×	×
11	Northumberland	A	×	×	×		
	,,	B				×	
12	Oxfordshire	A	×	×	×		
	,,	B	×	×	×	×	×
12/13	Oxfordshire–Berkshire	C		×	×	×	×
	Oxfordshire	D				×	
14	Somerset	A	×	×	×	×	×
	Somerset–Devon	B	×	×	×	×	×
15	Staffordshire	A	×				
	,,	B	×	×	×		
	,,	C		×	×	×	
16	Suffolk	A	×	×			
17	Sussex (West)	A	×	×	×	×	×
	,,	B	×	×	×	×	×
18	Warwickshire	A	×	×	×	×	×
	,,	B	×	×	×		
Totals		35	23	26	23	19	18

way at threshing. It seems likely that there is some tendency for farmers to select ricks which have the worst infestation in them to be threshed earlier in the season, a process which would not only provide a slight extra degree of control, but would make the figures from threshings higher than if ricks had been chosen at random. As a matter of fact, it is very doubtful whether this is at any time a dominant consideration influencing the choice of ricks to be threshed, because there are a number of other motives also operating, such as need for particular types of grain, convenience of the site, &c. Nevertheless, even though the tendency may be a slight one, it may possibly cause the samples discussed here to give a slightly magnified picture of the total infestation in the country.

3. RESULTS OF THE POPULATION SURVEY

(*a*) Rick types

Before comparing the results as a whole it is advisable to consider whether the rats and mice show any marked preference for one of the three types of corn, wheat, oats, or barley. It was found that both are commoner in wheat-ricks, though this is not so marked among the mice (Table 2). The average number of rats per rick or per infested rick shows a varying difference from year to year as between oats and barley and, as is shown by the grand totals, there is little to choose between them. According to these figures, ricks apparently tend to get occupied by rat populations in the frequency for wheat–oats–barley of 74:66:65, but to develop average infestations of the densities 7·8:5·2:5·0 for all ricks, and 10·6:7·8:7·7 for infested ricks, in each type. The reasons for such differences in preference for food or general environment, or in population success, or all three, can only be surmised. It is known that wheat seems to be the most generally successful bait for the brown rat, a fact which makes possible the use of wheat in standard census baiting before and after other baits. It has proved very difficult to attract rats living in certain environments, such as pure cereal stores, to any bait other than wheat soaked in water.

The house mouse, besides being slightly commoner in wheat than in oats, occurs more in wheat and oats than in barley. The average percentage of ricks infested from January to March for the five years is for wheat 94, for oats 92, and for barley 83. This order of occurrence is also shown by the number of ricks 'with over fifty mice', the percentages for wheat–oats–barley being 60:57:35; and it appears in each year except 1943, when the percentage of oat- and barley-ricks infested was practically the same, and in 1945 and 1947, when the percentage of oat-ricks 'with over fifty mice' was higher than that for wheat. It may therefore be concluded that, on the average, infestations of both rats and mice are more likely to develop in wheat-ricks and to reach higher densities than in either oat- or barley-ricks, and that barley-ricks have the lowest infestations of mice. It is possible that the sharp awns of barley act as a partial repellent.

These differences in rodent infestation in the main rick cereal types need to be taken into account when estimating trends over the five years of the survey, for variations in relative proportions of wheat-, oat-, and barley-ricks sampled from month to month or year to year will affect the average infestation figures. Thus an unusually high ratio of wheat-ricks would send

TABLE 2. *Rat and mouse infestation of wheat-, oat-, and barley-ricks in England (omitting Northumberland), January–March 1943–7*

		Rats				Mice			
Year	*No. of ricks*	*% ricks infested*	*No. of rats*	*Av. no. per infested rick*	*Av. no. per (all) ricks*	*% ricks infested*	*% of ricks with > 50 mice*	*% infested ricks with > 50 mice*	*% ricks poison baited*
1943									
Wheat	387	75·7	3,802	13·0	9·8	94·1	60·2	64·0	9·8
Oats	442	66·1	2,563	8·8	5·8	87·1	48·9	56·1	5·7
Barley	186	63·4	1,160	9·8	6·2	87·6	28·5	32·5	10·8
Total	1,015	69·3	7,525	10·7	7·4	89·9	49·5	55·0	8·2
1944									
Wheat	588	73·0	4,413	10·3	7·5	94·9	66·2	69·7	13·8
Oats	415	61·9	2,247	8·7	5·4	92·8	61·9	66·8	13·3
Barley	192	63·5	852	7·0	4·4	85·9	38·5	44·8	15·1
Total	1,195	67·6	7,512	9·3	6·3	92·7	60·3	65·0	13·8
1945									
Wheat	391	69·6	2,599	9·6	6·6	91·6	52·4	57·3	17·9
Oats	342	68·1	1,629	7·0	4·8	88·6	56·7	64·0	12·6
Barley	197	60·9	840	7·0	4·3	81·2	32·0	39·4	15·7
Total	930	67·2	5,068	8·1	5·4	88·3	49·7	56·3	15·5
1946									
Wheat	224	80·4	1,939	10·8	8·7	96·4	65·2	67·6	20·5
Oats	337	70·0	1,723	7·3	5·1	95·0	60·2	63·4	20·5
Barley	148	70·9	700	6·7	4·7	82·4	39·9	48·4	16·2
Total	709	73·5	4,362	8·4	6·2	92·8	57·5	62·0	19·6
1947									
Wheat	158	77·2	939	7·7	5·9	94·9	49·4	52·0	31·6
Oats	203	61·6	806	6·4	4·0	98·5	59·1	60·0	24·6
Barley	107	69·2	574	7·8	5·4	76·6	38·3	50·0	26·2
Total	468	68·6	2,319	7·2	5·0	92·3	51·1	55·3	27·4
1943–7 totals									
Wheat	1,748	74·1	13,692	10·6	7·8	94·2	60·1	63·9	16·3
Oats	1,739	65·7	8,968	7·8	5·2	91·6	56·9	62·2	11·0
Barley	830	64·9	4,126	7·7	5·0	83·4	34·9	42·0	15·9
Grand total	4,317	69·0	26,786	9·0	6·2	91·1	54·0	59·3	15·3

up the rat numbers, and a high ratio of barley-ricks would depress them. Such variations as occurred may have been due either to sampling errors or to real differences in the proportions of cereals grown (see, for example, § 3 (*f*))—probably to both. To guard against errors in interpretation of the raw figures, percentages of infestation and average numbers were converted also into a standard form, using as a basis the averaged total for ricks for the five years. These differ, however, so slightly from the raw figures that they have been omitted from further consideration. In no instance do

TABLE 3. *Rat and mouse infestation in ricks of cereals (wheat, oats, barley, and 'mixed'), and legumes in England (omitting Northumberland), January–June 1943–7*

				Rats				Mice		
Month	*No. of Counties*	*No. of Areas*	*No. of ricks*	*% of ricks infested*	*Total no. of rats*	*Av. no. of rats per infested rick*	*Av. no. of rats per (all) ricks*	*% of ricks infested*	*% of ricks with > 50 mice*	*% ricks poisoned*
All cereals 1943										
1	13	22	329	66·6	2,243	10·2	6·8	80·2	40·7	8·8
2	13	22	355	69·0	2,584	10·5	7·3	93·2	47·0	11·8
3	13	22	428	72·9	3,448	11·1	8·1	92·3	57·2	4·2
1–3	13	22	1,112	69·8	8,275	10·7	7·4	89·0	49·1	8·0
4	8	12	185	74·6	1,694	12·3	9·2	97·8	72·4	20·5
5	8	10	109	67·9	914	12·4	8·4	96·3	70·6	17·4
6	4	4	37	73·0	157	5·8	4·2	91·9	64·9	13·5
4–6	4–8	4–12	331	72·2	2,765	11·6	8·4	96·7	71·0	18·7
Peas and beans 1943										
1–3	13	22	25	68·0	185	10·9	7·4	76·0	28·0	12·0
4–6	4–9	4–12	1	[100·0]	2	[2·0]	[2·0]	[100·0]	[0·0]	[100·0]
All cereals 1944										
1	14	25	440	62·7	2,394	8·7	5·4	88·9	49·8	6·8
2	14	25	443	69·5	2,430	7·9	5·5	92·8	60·3	20·8
3	13	24	391	70·8	3,170	11·4	8·1	96·7	67·8	12·8
1–3	13–14	24–25	1,274	67·6	7,994	9·3	6·3	92·6	58·9	13·5
4	10	16	170	70·6	788	6·6	4·6	98·8	70·0	22·9
5	8	11	148	62·8	1,034	11·1	7·0	98·0	77·7	14·2
6	5	6	47	55·3	154	5·9	3·3	100·0	70·2	31·9
4–6	5–10	6–16	365	65·5	1,976	8·3	5·4	98·6	73·2	20·5
Peas and beans 1944										
1–3	13–14	24–25	32	56·3	174	9·7	5·4	75·0	21·9	6·3
4–6	5–10	6–16	3	[66·7]	17	[8·5]	[5·7]	[100·0]	[66·7]	[33·3]
All cereals 1945										
1	12	22	361	60·9	1,366	6·2	3·8	85·6	39·6	10·5
2	12	22	333	71·8	1,935	8·1	5·8	91·6	55·0	16·5
3	12	20	339	72·0	2,501	10·3	7·4	90·0	51·0	19·2
1–3	12	20–22	1,033	68·1	5,802	8·3	5·6	89·0	48·6	15·3
4	10	18	195	60·0	1,111	9·5	5·7	94·4	65·1	25·1
5	10	16	144	60·4	811	9·3	5·6	91·0	55·6	45·8
6	5	8	73	76·7	498	8·9	6·8	94·5	56·2	46·6
4–6	5–10	8–18	412	63·1	2,420	9·3	5·9	93·2	60·2	36·2
Peas and beans 1945										
1–3	12	20–22	34	64·7	379	17·2	11·1	64·7	23·5	14·7
4–5	5–10	8–18	7	[85·7]	20	[3·3]	[2·9]	[85·7]	[14·3]	[35·0]

TABLE 3 (*cont.*)

				Rats				*Mice*		
Month	*No. of Counties*	*No. of Areas*	*No. of ricks*	*% of ricks infested*	*Total no. of rats*	*Av. no. of rats per infested rick*	*Av. no. of rats per (all) ricks*	*% of ricks infested*	*% of ricks with > 50 mice*	*% ricks poisoned*
All cereals 1946										
1	12	18	297	72·4	1,525	7·1	5·1	89·2	45·5	18·9
2	12	17	245	71·4	1,522	8·7	6·2	95·1	61·6	15·5
3	12	16	240	77·5	1,724	9·3	7·2	100·0	63·3	21·7
1–3	12	16–18	782	73·7	4,771	8·3	6·1	94·4	56·0	18·7
4	11	15	145	76·6	1,137	10·2	7·8	93·1	62·1	25·5
5	10	12	133	70·7	935	9·9	7·0	96·2	61·7	37·6
6	6	7	49	77·6	436	11·5	8·9	100·0	85·7	28·6
4–6	6–11	7–15	327	74·3	2,508	10·3	7·7	95·4	65·4	30·9
Peas and beans 1946										
1–3	12	16–18	21	76·2	156	9·8	7·4	90·5	23·8	19·0
4–6	6–11	7–15	11	45·5	35	7·0	3·2	90·9	27·3	9·1
All cereals 1947										
1	12	15	212	69·8	998	6·7	4·7	89·2	35·4	19·3
2	12	17	157	73·9	919	7·9	5·9	94·3	61·8	28·7
3	12	16	148	64·2	746	7·9	5·0	94·6	54·7	20·8
1–3	12	15–17	517	69·4	2,663	7·4	5·2	92·3	48·9	25·1
4	11	17	206	75·2	2,722	17·6	13·1	93·7	50·5	34·5
5	11	15	168	72·0	2,225	18·4	13·2	95·8	60·7	36·3
6	6	10	78	66·7	482	9·3	6·2	91·0	69·2	33·3
4–6	6–11	10–17	452	72·6	5,429	16·6	11·9	94·0	57·5	35·0
Peas and beans 1947										
1–3	12	15–17	19	89·5	152	8·9	8·0	68·4	15·8	26·3
4–6	6–11	10–17	17	58·8	224	22·4	13·2	70·6	0·0	17·6
1943–7 Totals (cereal-ricks)										
1	..	..	1,639	65·8	8,526	7·9	5·2	86·5	43·1	11·8
2	..	..	1,533	70·6	9,390	8·7	6·1	93·2	50·6	17·7
3	..	..	1,546	72·1	11,589	10·4	7·5	94·1	59·2	14·8
1–3	..	..	4,718	69·4	29,505	9·0	6·3	91·2	50·8	14·7
4	..	..	901	71·1	7,442	11·6	8·3	96·6	63·7	26·0
5	..	..	702	66·8	5,919	12·6	8·4	94·4	65·1	30·9
6	..	..	284	70·0	1,737	8·7	6·1	94·1	68·4	33·1
4–6	..	..	1,887	69·4	15,098	11·5	8·0	95·4	64·9	28·9
Grand total			6,605	69·4	44,603	9·7	6·8	92·4	54·8	18·8

they affect any conclusion arrived at here. The records for pea- and bean-ricks do not, after allowance is made for the very small number of ricks in the samples, suggest any substantial difference in occupation by rats, but the house mouse populations are much lower than in cereal-ricks; or even than in barley-ricks alone (Table 3).

(*b*) Geographical differences

The records obtained from each of the areas sampled from January to June 1943–7 were summarized separately in tables that are deposited for reference in the Bureau. The original idea of trying to get two different and non-adjacent areas from each county was to have some check on local differences. As there is sometimes considerable variation within the county, it is necessary to be cautious in drawing conclusions about wider geographical variations. No clear geographical zonation was discovered, though there was some indication that certain counties were not so consistently or heavily infested as others. The chief conclusion was that rat and mouse infestations in ricks occur throughout England on a scale sufficient to need control measures, and we therefore obtain a clear answer to the first question that the inquiry was designed to meet.

The combined figures for all counties except Northumberland (which is discussed separately in § 3 (*e*)) are given in Table 3, for the first six months of each of the five years, and divided into 'all cereals' and 'peas and beans'. In the analyses that follow, emphasis is put chiefly on the figures for January to March. This is because practically all the threshing tackles were operating during it, whereas they finished threshing at varying dates in the following three months, so that the April to June figures are less homogeneous and more liable to accidental weighting by results from particular areas.

The highest actual numbers of rats recorded in any rick between January and March in the three months of the five years are given in Table 4. These figures probably give a good idea of the limits which the most successful rick rat population might reach in England before the end of March in these years.

TABLE 4. *Maximum number of rats in any cereal-rick, January, February, and March 1943–7*

	1943	*1944*	*1945*	*1946*	*1947*	*Average 1943–7*
January . . .	80	150	67	101	89	97
February . . .	102	90	108	120	70	98
March . . .	150	130	101	115	35	106

As so much intensive research concerning corn-rick rat populations has been carried out in the Oxford region, particularly from 1939–43, it is of general interest to know whether the scale of these populations is typical of that found generally in the country. The records for the Oxford region for 1941 and 1942 were obtained through the research work of Venables, who had different recorders from those in 1943. These figures have been analysed to conform with the methods of the national survey and are given in Table 5. As far as is known, none of these ricks had been poison baited in either season.

TABLE 5. *Rat and mouse infestation of sample cereal-ricks in the Oxford region (Oxfordshire, Berkshire, and Buckinghamshire), January–March 1941 and 1942*

		Rats					*Mice*		
Year	*Month*	*No. of ricks*	*% of ricks infested*	*Total no. of rats*	*Av. no. of rats per infested rick*	*Av. no. of rats per (all) ricks*	*No. of ricks*	*% of ricks infested*	*% of ricks with > 50 mice*
1941	1	20	55·0	114	10·4	5·7	10	90·0	20·0
	2	35	62·9	141	6·4	4·0	14	64·3	7·1
	3	39	53·8	203	9·7	5·2	20	80·0	25·0
	1–3	**94**	**57·4**	**458**	**8·5**	**4·9**	**44**	**77·3**	**18·2**
1942	1	39	59·0	263	11·4	6·7	19	42·1	0·0
	2	43	55·8	556	23·2	12·9	22	54·5	4·6
	3	42	54·8	246	10·7	5·9	22	68·2	4·6
	1–3	**124**	**56·5**	**1,065**	**15·2**	**8·6**	**63**	**55·5**	**3·2**

In comparing the rat numbers for the ricks of the Oxford region in January–March 1941 and 1942, with those for the national survey in the same months of 1943, two points have to be remembered: (*a*) the region covers different parts of Oxfordshire from those of the 1943 inquiry, (*b*) we are dealing with different years. It is therefore obvious that we cannot expect to obtain any exact comparison. Nevertheless, the average percentages of cereal-ricks infested in January–March (57·4% in 1941, 56·5% in 1942), are not very far different from the average for the whole country in January–March 1943 (69·8%); and the average numbers of rats per infested rick and in all ricks (8·5 and 4·9 for 1941, 15·2 and 8·6 for 1942) lie well within the range of values found in various counties over the rest of the country in 1943 (infested ricks 5·4–18·7; all ricks 2·3–13·8). The averages of these Oxford figures for the two years, giving 11·9 for infested ricks and 6·8 for all ricks, lie remarkably close to the national survey averages for 1943 of 10·7 and 7·4 respectively. It can therefore be said that the Oxford region samples examined in January–March 1941 and 1942 had rat infestations typical of the country as a whole in the same period of 1943. This answers part of the second aim of the inquiry.

(*c*) Seasonal differences

Table 3 shows the average monthly figures for rat and mouse infestation in cereal-ricks, and 3-monthly averages (on much smaller numbers of ricks) for legumes. Even as early in the winter as January the rat infestations have almost reached their ceiling occupation index (percentage of ricks infested), the net percentage differences between January and March in the five years being +6·3, +8·1, +11·1, +5·1, and −5·6, average from the total figures +6·3. High occupation was maintained, with minor fluctuations, until the end of the threshing season, a fact that contradicts the widespread belief among country people that there is a complete exodus of rats in the spring (about April) from ricks into the surrounding fields.

We do not yet know how this distribution of occupation becomes stabilized, i.e. how the balance of immigration and emigration is maintained. We know that rats may sometimes enter a rick in quite large numbers immediately after it is built at harvest time, say in September, and that colonization of new ricks certainly goes on during the next few months at least. There is a general belief, and there are some direct scientific observations, that rats come into the ricks and farmyards from the fields and hedges in greater numbers when the first hard winter frosts are felt, say in November. The simplest view would be that nearly all stray field rats have entered ricks (or other crop stacks like potato clamps) and farm buildings by the end of the year, and thereafter maintain fairly definite rick or rick-group colonies, and that a small percentage of ricks remain unoccupied either through isolation, unsuitability, or successful control by man. But the picture is probably not as simple as this, because it has to be remembered that the statistics we have are not for the same populations measured at different times, but for a succession of different ricks.

Although the national survey suggests that very little increase in occupation occurs after January, the records obtained by Venables and Leslie (1942) for the Oxford region for the season 1940–1 showed that the percentage of rick groups occupied went on increasing continuously from the period 20 August–16 September (0%) until the period 2 April–27 May (66·7%), with a rather sharp rise in November–December. The two sets of data are not entirely comparable, since the 1940–1 records refer to rick groups, and the national ones to individual ricks; and the Oxford rick numbers were very small (15–36 in any one period), as compared with hundreds in the national survey; but the discrepancy cannot at present be explained.

Turning to the density figures, we find that the average number of rats per infested rick goes on rising from January to March, the net percentage difference in the five years being 8·8, 31·0, 66·6, 31·0, and 17·9, the average of the five years' totals being 31·6. This represents (supposing the sampling to be adequate) the difference in numbers per infested rick built up in 2 months—taking the middle of January and March as pivotal points. We know from analyses of a number of rick rat bodies from the Oxford district over several seasons (partly referred to by Venables and Leslie, 1942 and fully analysed by Leslie *et al.*, 1952), that rats continued to breed all through the winter and spring inside corn-ricks. The figure of 31·6% given above does not include the nestling population, which would perhaps have been increasing at a relatively higher rate.

Perhaps the figure that best sums up the combined results of these seasonal influences, known or suspected, is the average number of rats per (all) ricks, for the five years as a whole (Table 3). These show a steady rise until March and a net increase between January and March of 44·2%. The density is maintained, or even slightly increased, up to the end of May, and drops only slightly in June.

House mice also reach a remarkably high occupation index by January, sometimes nearly 90%, and this usually reached its peak by February. The only indication of density changes is that provided by the percentage of ricks with over fifty mice, which shows a steady rise, usually to a peak in April, May, or June. A fuller discussion of seasonal changes and other ecology of corn-rick house mouse populations based on local investigations round Oxford will be found in Southern and Laurie (1946), where a few of the national survey figures are also included. Their highest count was 1,996 mice in a June rick. It is not possible to say much about seasonal changes of rats and mice in pea- and bean-ricks, but evidently they may remain occupied from January until the end of the season.

(*d*) Year to year changes in England generally

House mice remained at constantly high rates of occupation, with more than half the ricks having over fifty mice: their slight annual variations need not be discussed here. There was no general trend up or down in the percentage of ricks infested with rats. Thus, the figures for January–March were 69·8% in 1943 and 69·4% in 1947, those for April–June 72·2% in 1943 and 72·6% in 1947. The fluctuations in between were small. There was, however, a slow decline in the numbers per infested rick, for January–March, from 10·7 in 1943 to 7·4 in 1947. The net decrease, summarized by the density over all ricks, was from 7·4 to 5·2, i.e. about 30%. In the period April–June there was, on the other hand, an actual increase from 8·4 in 1943 to 11·9 in 1947, although the average number of ricks poison baited in the four years was 14·7% for January–March and 18·8% in April–June. Taking into account the approximate nature of our sampling, with some variations in areas, observers, and seasonal conditions, we can only safely conclude that the rat population in English corn-ricks remained high in all five years, and that no marked decline can be proved from the figures.

Corn-ricks afford only temporary harbourage to rats, which are part of the total farm population from which they are derived in the autumn, and to which some of them and their descendants return next year. The two special features of the corn-rick populations are that they breed at a much higher rate in winter than those in other farm habitats, and that they are not only protected to a great extent from natural enemies and the hazards of climate, but are relatively immune from human control activities.

It is explained in Chapter 10 that although a high rate of kill can be obtained by poison baiting rats in corn-ricks if one baits at all accessible points, the risk of residual poison remaining in the grain after threshing still makes it necessary to limit baiting to holes at the base of the rick. This is the official advisory policy of the M.A.F.; though it has not been followed every-where, we may assume that most of the ricks reported as 'poisoned' were probably treated by the limited ground hole-baiting method.

In 1943, the first year of the present inquiry, general use of poison baiting by the modern methods introduced by the Bureau had scarcely begun; in particular, zinc phosphide was only just coming into circulation. In January–March 1943 only 8% of the sampled ricks had been poison baited. The omission of thirty-three ricks treated in West Sussex would reduce this to only 5·7%. There was a steady increase up to 25% in 1947. In spite of this, the rick populations remained high.

The January–March figures for the five years were re-analysed into poisoned and unpoisoned ricks. The differences in infestation are so small that the complete table of them is omitted here. The mean rat density for all ricks was 9·4 for poisoned, and 8·9 for unpoisoned. This confirms the idea that limited treatment is ineffective after the rats enter the ricks.

But the question remains why the campaign against farm rats in general had not by 1947 substantially lowered the numbers arriving to enter ricks in the autumn. One factor maintaining the population must certainly be the impressive breeding output of rick rats during the winter and spring. We still have no safe, effective, and economical method of killing these populations in corn-ricks. The Bureau invented two effective methods, but one (poison baiting) is not quite safe enough, and the other (carbon dioxide gassing) is too uneconomical and laborious. The solution of this problem lies right at the centre of farm rat control.

In the last year of the inquiry the recorders distinguished between ricks built in fields and in farmyards. The occupation rates and numbers per rick show hardly any difference between these two classes of habitat, although it is certain that considerable poisoning and other control must have been done in many of the farm premises. It seems very unlikely that control measures had been either so inefficient or so evenly spread between fields and farm premises as to account for the rick figures. Furthermore, instances have been observed by the Bureau of farms on which control has reduced rats to a low level except in the rick-yards. It is possible that even in a farm yard the rick rats form exclusive colonies that do not leave the ricks much. However that may be, these figures further emphasize the need for a good means of killing rats in ricks.

(*e*) Populations in Northumberland

In this county most of the ricks are very small and it was thought best to give the results separately (Table 6). The figures for 1943–5 were all collected by one man, Mr. J. W. Taylor, an exceptionally good observer who took much trouble to supply information not only on rodents, but about such of their enemies as were encountered in the ricks. In the fourth year he ceased business, and it was necessary to change to another man, who supplied results for a further year: as these were mainly from a differ-

TABLE 6. *Rat and mouse infestation in a sample of Northumberland cereal-ricks (wheat, oats, and barley combined, omitting mixed cereals), January–March 1943–6*

	Rats					Mice			
Year	*No. of ricks*	*% of ricks infested*	*No. of rats*	*Av. no. per infested rick*	*Av. no. per (all) ricks*	*No. of ricks*	*% of ricks infested*	*% of ricks with > 50 mice*	*% of ricks poisoned*
1943	192	56	852	7·9	4·4	176	88	28	48
1944	146	63	975	10·6	6·7	146	90	23	57
1945	85	55	320	6·8	3·8	85	62	20	75

ent area, they are omitted here. Mr. Taylor informed us that most (though not all) of the ricks were small round ones yielding 23–30 bags of corn, of which five or six might be threshed in a day, instead of only one or two large ones as is usually the case elsewhere. The rates of infestation for all ricks were high compared with most other counties reporting, if one takes into account the smallness of the ricks. The poison campaign was carried on vigorously in Northumberland, but our data do not cover enough years for its effects to be measured reliably.

(*f*) Changes in corn acreage

The total area of cereals grown and the relative amounts of each type were changing throughout the period of this inquiry. Such changes might affect rat numbers in at least two ways. Higher absolute cereal acreage (e.g. at the expense of pasture) would tend to increase the total numbers of rats on a farm; and relatively higher wheat acreage would tend eventually to increase the number of rats per infested rick, provided the expansion in number of new ricks was not so rapid as to 'dilute' the rats among the more rick habitats available.

The figures for the acreage of cereals in England (only) from 1939 to 1946 in Table 7, were kindly supplied by the M.A.F. The total acreage reached its peak in 1943, as did that of wheat. Oats had two fluctuations with peaks in 1942 and 1945. Barley increased steadily throughout. The acreage planted broadly determines the number of ricks in the following winter and spring, so that the figure for rats in January–February 1943 has to be compared with the acreage for 1942, and so on.

We have already said that the annual variations in the relative numbers of wheat-, oat-, and barley-ricks in our samples had a negligible effect upon the average rat numbers found. Table 7 proves that the percentage of wheat in our samples followed fairly closely (as might be expected) the percentage of wheat in the total acreage of cereals in England in each previous year. There is no very apparent connexion in detail between the wheat ratio and the rat numbers. This does not prove that wheat changes have not influenced

TABLE 7. *Thousands of acres of cereals in England (only) in June 1939–46*

Year:	*1939*	*1940*	*1941*	*1942*	*1943*	*1944*	*1945*	*1946*
All (including 'mixed') cereals.	3,840	4,894	5,945	6,214	6,981	6,927	6,435	6,152
Wheat . .	1,670	1,675	2,077	2,308	3,147	2,950	2,121	1,940
Oats . . .	1,198	1,809	2,076	2,096	1,830	1,878	1,969	1,843
Barley. . .	888	1,184	1,292	1,301	1,472	1,641	1,916	1,945
*% wheat acreage	44·5	35·9	38·1	40·5	48·8	45·6	35·3	33·9
*% wheat-ricks in samples (–1 year)	..	..	..	38·1	49·2	42·0	31·6	33·8
*Av. no. of rats, all ricks, Jan.–Mar. (–1 year) . .	..	..	..	7·4	6·3	5·6	6·1	5·2

* Out of total wheat, oats, and barley, omitting 'mixed' cereals.

rat populations, only that they have not been the dominant influence. We conclude that if there is any influence of changing wheat acreage it cannot be demonstrated, but it would be expected to reduce the apparent success of any measures of control, as judged by rick rat densities.

4. ESTIMATE OF MINIMUM GRAIN CONSUMPTION IN RICKS

An attempt has been made, using the figures for the first 3 months of 1943 as an example, to estimate the rate of consumption and consequent loss of grain in corn-ricks caused by rat and mouse populations. Using the figures for consumption of dry food by *R. norvegicus* worked out by Leslie (Ch. 6), which should be applicable to rats living on a grain diet, and some provisional figures for the house mouse determined by Southern (Southern and Laurie, 1946, p. 148), we can get an idea of the minimum daily food loss in ricks containing a given rat and mouse population. (Leslie's calculation allowed for the observed weight (age) distribution and the differential food consumption according to weight; no such corrections can at present be made for mouse populations in ricks.) The average daily consumption of dry wheat per head of rats in corn-ricks in the Oxford region throughout the season was calculated to be about 24 g. Therefore every million rats consumes about 23·6 tons a day, or 2,124 tons in 3 months (taken as 90 days). This figure takes no account of the undoubtedly large amount spoiled and wasted, the ratio of which to actual consumption is still unknown. The laboratory determinations for wheat are applied to the consumption of oats and barley, and of legumes sometimes mixed with them. An adult house mouse eats about 3·4 g. of dry wheat per day, i.e. the consumption by seven mice equals that of one rat. Therefore every million adult mice consumes about 3·4 tons a day, or 306 tons in 3 months. The amount of additional wastage by mice is almost certainly much greater than that by rats.

The rate of consumption can be assessed in a different form: the total amount of loss occurring in 3 months in every 100,000 ricks standing on

1 January 1943. For this calculation we assume that the density of rats was really about the same in January, February, and March and that the rate of threshing was a steady linear one. The first assumption is broadly confirmed by the experience of the next 4 years and is probably near enough for the present purpose, which is to establish the general scale of rat damage. The second assumption is borne out by the numbers of ricks threshed per month, per threshing tackle, and by similar figures compiled by Leslie for the Oxford region. It is also necessary to assume that commercial and W.A.E.C. tackles operated at the same rate and sampled the ricks in the same manner as privately owned (estate and farm) tackles, about which we have no national records.

We require to know what proportion of every 100,000 ricks standing on 1 January 1943 was still standing on 1 April. This can be calculated from the sample (13 tackles) that supplied records right to the end of threshing, which were still operating on 1 April. Eight hundred and twenty-four ricks were threshed before 1 April, and 232 afterwards, i.e. 22% of the total of 1,056 ricks standing on 1 January were still standing on 1 April. In every 100,000 ricks standing on 1 January, 78,000 would therefore be threshed during the next 3 months, leaving 22,000 standing on 1 April. With a linear rate of threshing, this means that on the average 61,000 ricks were standing for the whole period. The total consumption of grain by rats (allowing the assumptions mentioned above) would therefore be

$$\frac{61{,}000\times 7\times 24}{1{,}016{,}000}$$

or 10·1 tons per day (there being 7 rats per rick, and 24 g. daily grain consumption per rat, the figure underneath giving conversion of grammes into ordinary (long) tons). For the 3 months it comes to about 909 tons. (Leslie's calculation of food consumption of rick rat populations assumed the lower limit for an 'active' rat to be 45 g. body weight; whereas, weighing being out of the question in the national inquiry, the 'active' rat was defined as anything larger than a pink nestling. This would probably make 909 tons a slight over-estimate, in so far as the populations counted would have included a larger proportion of nestling rats than those used in Leslie's calculations.)

Another factor affecting the rate of consumption should be mentioned, although we cannot estimate its actual effect in the field. As shown in Chapter 4, § 7, laboratory rats may greatly increase their intake of food during lactation—sometimes as much as 3 times. This means that the presence of nestlings in a rick will almost certainly send up the food consumption of their mothers above the average figure used in the preceding calculations (see Russell, 1948, for a review of this question). Leslie's analyses (Leslie *et al.*, 1952) of the breeding rates of populations of rats in corn-ricks in the Oxford region revealed that adult females were in excess of males, and that something like a quarter of the females were pregnant during the first 3 months of the year (the percentage varying with the exact period and with the weight of the female). It is evident therefore that our estimate of 909 tons is well below reality, even for direct consumption alone.

The calculation for the rate of grain consumption by mice must necessarily be extremely approximate, and represents a minimum figure for consumption, since no allowance can be made for the large number of ricks with well over fifty mice or those with 2–49 mice. The precentage of ricks with 'over fifty mice' (which we shall take as equivalent to 'fifty or more mice') apparently increased through the 3 months from 40·7 to 57·2. For the present rough calculation it will be assumed that the average figure, 49·1%, applied to the whole period. Besides these ricks, there was a further 39·9% which had at least one, but not more than fifty mice in. The total consumption in the 3 months would be at least

$$\frac{61{,}000\times 49{\cdot}1\times 3{\cdot}4\times 50}{100\times 1{,}016{,}000}$$

plus

$$\frac{61{,}000\times 39{\cdot}9\times 3{\cdot}4\times 1}{100\times 1{,}016{,}000}$$

or 5·01 plus 0·08 = 5·09 tons per day. This comes to about 458 tons in the 3 months.

An estimate of the total real loss of grain in January–March 1943, for 100,000 ricks would therefore include the following items:

Consumption by rats	At least 909 tons
Wastage by rats	Unknown, large
Consumption by mice (known)	458 tons
Consumption by mice in ricks with 2–49 and over 50 per rick	Unknown, very large
Wastage by mice	,,
Total	At least 1,360 tons.

In the early part of the winter, and especially before the first severe frosts, rats continue to inhabit holes in banks near ricks, though feeding partly or wholly in the ricks. It is not known how commonly they continue to do this in January–March. Any such rats, escaping the counts at threshing, would further increase the total loss of grain. A certain amount of the wastage from rodents in the ricks will go back into circulation through the gleaning by poultry on rick sites, or in 'tailings', though it will be lost for direct use by man. We have no census figures for the country in the period before January, but it is known from the Oxford region that the infestation of ricks by rats and mice is not generally serious before November, the December densities reaching the same order of level as those in January–March. The January–March figures give some measure of the situation at the time of year when there is the greatest number of infested ricks standing, but do not represent the total seasonal damage.

It must be stressed that the calculations given above are at best, very rough; nevertheless, they give some conception of the scale of rats and mice as corn-rick pests. The economic status of these populations cannot be judged solely on the direct damage they do in ricks, since the latter afford reservoirs, until recently relatively inaccessible to control until threshing time, from which rats can colonize other farm habitats and do further damage both in and outside the corn-rick season. The same thing applies to mice, though to a much lesser extent, since they do not at present appear to be a major source of economic damage on farms apart from their depredations in ricks and in corn-fields themselves.

The nature of the loss of human food can be stated in another way. It is quite common to see four ricks standing in a group in fields or farm yard. In February 1943, on the average, each group would have held about thirty rats above nestling age. Leslie's figure for the food consumption per 'active' rat in a rick population with a certain characteristic age distribution is about 24 g. per day, and this is about 3% of a resting man's basic requirements of 2,400 cals., which is probably of the same order as the actual food intake of an average human being if all age groups are included. On the average thirty-three rats in a rick would therefore be eating 2,400 cals. a day. Therefore a typical group of four ricks would be losing from rats at least that amount of stored human food a day, i.e. one human ration, since wastage is also involved. The addition of mouse damage, as we have seen, probably more than doubles this.

5. THE TOTAL SIZE OF CORN-RICK RAT POPULATIONS IN ENGLAND

Statements about the total numbers of rats in the country are less confidently made than they used to be. All such estimates made hitherto are fallacious, being either based upon rough calculations of the natural reproductive rate of rats that take no account of mortality, or else sheer guesses at the total population. If we knew the number and type of corn-ricks built, and their seasonal history, it would be possible to make some estimate of the order of size of winter corn-rick rat populations in 1943–7. Although this information does not exist, we can give a partial figure for rats encountered at threshing which at any rate gives an indication of the very large size of the whole population.

We have used the census of threshing tackles done in certain years. No such census was taken in 1943, so we have based the following calculation on 1944, for which the M.A.F. (1947) has published some figures. The total estimated number of portable threshing tackles in April 1944, owned by occupiers, contractors, and W.A.E.C., in England, was 10,710, of which 8,500 were owned by private occupiers. We shall assume that the 2,210 run by firms and the committees were operated up to the end of the season for the same average proportion of the time as were the twenty-six supplying the results of our survey in 1944. These twenty-six tackles counted altogether 9,970 rats in cereal-ricks between January and June. (Most of the tackles were working up to at least the end of March, and gradually dropped off as threshing in their areas finished.) Supposing the sampling to be adequate, the 2,210 tackles in England would therefore have encountered (and mostly killed) about 847,000 rats.

We cannot give any figure for the number of rats encountered before the New Year, because no field records were made then except in the Oxford district. The Oxford surveys for 1939–42 indicate, however, that rat infestation actually in the ricks did not reach January–March levels until December, so that the total numbers of rats encountered at threshing in September–December would almost certainly be lower than those in the next 3 months. (There would, however, have been some additional rats, living in banks but feeding in the ricks at this period, that would have escaped the counts.) But it would seem safe to estimate the total number of rats encountered by commercial and committee tackles in England in the whole threshing season September 1943 to, say, June 1944, as over one million but less than two millions. To this would have to be added those encountered in Wales and Scotland.

No estimate can be made of the numbers found by the 8,500 private owners of tackles, because these are not operated continuously. But when we consider the figures for one such tackle on the A.R.C.'s Estate at Compton, Berkshire (Ch. 10), where 770, 513, 826 rats were caught in three seasons (prior to the introduction of rick poison baiting) it would seem probable that the total numbers encountered by private tackles must be very large, especially as the tackle belonging to one estate may sometimes be lent to others.

These calculations give a rick rat population encountered during threshings (and perhaps largely destroyed at those times) of the order of several millions. But this figure does not imply that several million rats were ever living at one moment, or that they were present all through the season. The total rick rat population is very low immediately after harvest, and rises through the early winter (by immigration and breeding) until the cumulative effect of threshing begins to counterbalance the density of rats, and the total population (irrespective of whether the density per rick is higher) begins to fall, reaching a low number again by summer.

We could only convert such estimates of 'total rats encountered at threshing' into total food consumption by knowing the life-table of the rats. If we knew the total acreage of corn per rick (which would need special sampling, complicated by the variable size of ricks and many local factors), and the fraction of the total known acreage threshed 'off the field' by tackles or by combine harvesters (i.e. the amount that never becomes ricks) it would perhaps be possible to calculate the number of ricks standing at the beginning of the season. This, combined with a sample rat census at threshing throughout a whole season, might give a basis for estimating total rat numbers and food consumption.

6. SUMMARY

1. Sample censuses of the corn-rick rat population of England were done by threshing-tackle foremen at threshing time on 6,605 cereal-ricks and 170 legume ricks. House mouse infestation was also noted; and whether or not the ricks had been poison baited.

2. The inquiry ran for five years, from 1 January until the end of the threshing season.

3. Both rat and mouse infestation was general, and similar in scale to that previously studied in detail in the Oxford region. For the whole five years the average percentage of ricks occupied by rats in January to March was 69·4, the average number per infested rick 9·0, and (combining both figures) the average number in all ricks 6·3. For house mice, the average percentage of ricks occupied in January to March was very high—91·2, and the average percentage number estimated to contain over fifty mice 52·8.

4. Wheat-ricks had higher rat infestation than oat- or barley-ricks; and barley-ricks had much lower house mouse infestation than either wheat or oats, which were about equal. Pea- and bean-ricks had rates similar to those of cereals, except that the numbers of ricks with over fifty mice were lower even than in barley.

5. The numbers of rats per rick began to approach a ceiling density in and after January, the average increase between January and March in infested ricks being only about 32%. House mice reached their ceiling occupation index by about February, when nearly every rick was colonized.

6. During the five years the average number of rats in all ricks for January to March had only decreased about 30% in spite of the poisoning campaign on surrounding farm country. For the period April–June it had increased. It is concluded that numbers in the ricks had remained high, in spite of the expansion of poison baiting on farms.

7. A partial estimate of the amount of grain (calculated as wheat) consumed by rats and mice in every 100,000 ricks standing on 1 January 1943 and in the following 3 months, gave a minimum of 1,360 tons, the total damage being considerably more than this. It was also calculated that in February 1943 an average group of four corn-ricks would be losing the equivalent in calories of one human ration daily from rat consumption alone.

8. The total number of rats encountered at threshing time by commercial and county committee threshing tackles in England in one season was between one and two millions. The total numbers killed at threshing by all tackles in Great Britain must have run into several millions per year.

9. Corn-ricks are the most important habitat for rural rats and house mice.

REFERENCES

LAURIE, E. M. O. (1946). 'The reproduction of the house-mouse (*Mus musculus*) living in different environments.' Proc. Roy. Soc. B, 133: 248–81.

LESLIE, P. H., VENABLES, U. M., & VENABLES, L. S. V. (1952). 'The fertility and population structure of the brown rat (*Rattus norvegicus*) in corn-ricks and some other habitats.' Proc. Zool. Soc. Lond. 122: 187–238.

MINISTRY OF AGRICULTURE & FISHERIES (1947). 'Agricultural statistics, 1939–1944. England and Wales. Part 1.' p. 227.

RUSSELL, F. C. (1948). 'Diet in relation to reproduction and the viability of the young. Part I. Rats and other laboratory animals.' Tech. Comm. Bur. Anim. Nutrit., Aberd. No. 16: 1–98.

SOUTHERN, H. N., & LAURIE, E. M. O. (1946). 'The house-mouse (*Mus musculus*) in corn ricks.' J. Anim. Ecol. 15: 134–49.

VENABLES, L. S. V., & LESLIE, P. H. (1942). 'The rat and mouse populations of corn ricks.' J. Anim. Ecol. 11: 44–68.

12

THE CONTROL OF RATS IN SEWERS

By J. S. PERRY

I. INTRODUCTION

(*a*) Sewer systems

IN a typical modern system, porcelain pipes carry sewage from individual buildings into a pipe running along the street, which joins up with others until the effluent is collected into a main sewer and carried to a pumping station, where it is brought to the surface and disposed of. The porcelain pipes that form the drains and smaller sewers are usually 9 or 12 in. diameter, while the larger sewers, ovoid in section, are usually of brick and are called 'barrels'.

In some towns, two separate systems remove waste liquids, the 'foul' sewerage system removing all sewage and industrial effluent, and the surface water system removing rain water, &c., from the street drains. This is the case in Oxford (White, 1877, 1902), while in London, within the area of the L.C.C. main drainage system, sewage and surface water are carried down the same channels.

In general, where pipes or barrels are not large enough to permit a man to walk through them, they are laid in straight lines, and where it is necessary to turn a corner, or where two or more meet, there is a manhole or a lamphole. Manholes are rectangular brick shafts leading to the sewers from street level, with ladders or step irons. Lampholes, which are smaller shafts down which a light can be lowered to sewer level, are used when searching for blockages; they have not been found useful in rat control.

Where a channel runs through a manhole shaft, it is open, and in the case of a small sewer it is flanked by slightly sloping 'benches' which extend to the walls of the shaft. In rat control operations bait is placed on the benches, which seldom slope too much to prevent this. When the manhole leads to a larger sewer, such as a brick 'barrel', there is usually no bench, the greatest width of the barrel being the width of the manhole. It is therefore impossible to bait at such manholes unless a tray (§ 6) is fixed to the wall of the shaft to hold the bait. Sewers usually run below the centre of the street with manholes opening directly above them, but in some cases, as in central London, the manholes are in the pavement, with a slightly sloping 'gallery' giving access to the sewer. Bait can be laid at the base of the manhole on the floor of the gallery.

The manhole aperture is closed at the top by a cover. The covers are necessarily fairly heavy and lifting them constitutes a considerable proportion of the labour of a rat control operation. Before any such operations are undertaken all the manholes in the area with which it is proposed to deal should be visited and loosened.

Another requisite for rational control measures is a plan of the sewer system, and records can best be kept if the manholes are numbered. If control measures are to be carried out over a fairly wide area the street route to be followed should be determined beforehand—for the operators' purpose a street map on which the manholes are marked and numbered is most useful.

Some idea of the extent of a sewer system in a big town area can be gained from the fact that during a campaign carried out simultaneously in 44 boroughs of London, the area involved, which was that covered by the L.C.C. main drainage system, was over 91,000 acres. Over 32,000 manholes were baited, covering some 3,500 miles of sewer.

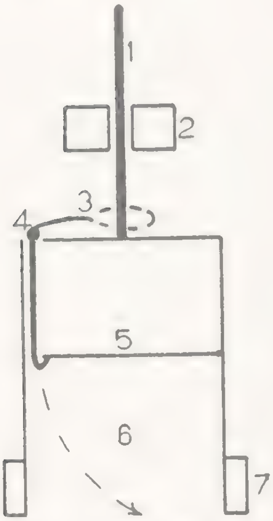


FIG. 1. Longitudinal section of bait depositor. (1) Cord. (2) Messenger. (3) Release mechanism pivoted at (4) and with spring tension at inside of upper (bait) compartment. (5) Trap door which releases bait into an open lower compartment (6) to prevent scattering. (7) Stabilizing weights. (Slightly modified from the original model.)

(*b*) Bait depositor

In small-scale experiments surplus prebaits were placed by hand and weighed at the bottom of the shaft of the manholes; but in practice, to avoid the great labour of the climbing, the original of the apparatus in Fig. 1 was designed by Chitty. It consists of a tin can of rectangular cross-section divided in half by a trap door controlled by a wire release mechanism. Bait is placed inside the enclosed portion and the box is lowered on to the bench, open end down, by means of a cord (Plate 7). A wooden messenger is then slid down the cord to strike and release mechanism. The bait falls out and is prevented by the lower half of the box from scattering too much. Heavy metal attachments are needed to keep the box steady while the cord is held taut. The principle is the reverse of that used in ecological sampling of the bottom of the sea or lakes by means of the Petersen grab and Ekman dredge.

Large numbers of these 'bait depositors' were constructed by the M.O.F. according to a slightly modified design described in their publication (1946).

(*c*) Review of experiments

The present account has been compiled from the reports of various investigations carried out by members of the Bureau between 1940 and 1945. The problem was first surveyed by Hewer, who later, as Chief Rodent

Officer to the Infestation Division, M.O.F., directed the large-scale clearance operations in London and elsewhere. Hewer came to the conclusion that the breeding sites of the sewer rats were in the many 'dead ends', defective house drains and defective places in sewers where the rats can get out into the ground surrounding the sewer. He went on to experiment with the possibilities of baiting in air-locked pipes that could be maintained in the sewer system, the airlock preventing flooding. This line of investigation was dropped when it was shown that prebaiting at manholes was extremely effective. Hewer also investigated the deterioration of baits (biscuits of various kinds) through the growth of moulds.

These investigations were followed up in 1942–3 by experiments made in Oxford by Chitty and Freeman, in the course of which the bait depositor was devised. Fifty-six manholes were treated, moist sausage-rusk was proved to be a suitable bait and prebaiting to be a practical method of controlling sewer rats. The methods used in subsequent large-scale work by the M.O.F., were based on the conclusions drawn from these experiments in Oxford. The Ministry's standard system consisted of 4 days' prebaiting with poisoning on the fifth day, these latter baits being left down for at least 48 hours.

A large-scale clearance campaign, directed by the M.O.F., was carried out in the area of the L.C.C. main drainage system. The extent of these operations has already been described here and by Barnett (1947). Observations were also made, by Watson and myself, during and after the campaign in the City of London and in Poplar. Some special investigations have been carried out by the Bureau in co-operation with the M.O.F. Of two experiments in Reading (by myself and S. A. Barnett of the M.O.F.), the first compared the effect of direct poisoning with that of a standard treatment, and the second was a trial of a 1-3-5 day treatment. In an experiment at Ealing (S. A. Barnett and Mrs. Flatt) the effect of two successive standard treatments was compared with that of two successive treatments by direct poisoning.

Grateful acknowledgement is made to Mr. J. Campbell Riddell, the city engineer of Oxford, and his staff, for co-operation in the initial experiments, and to many other municipal authorities for help in later work elsewhere.

2. SEWERS AS A HABITAT FOR RATS

Most house drains are cut off from the street sewer by an interceptor or water trap, and when rats have been observed to come into a building from the sewer, it has usually been found that the interceptor has dried up. It is otherwise rare to find evidence of rats in the domestic drain itself. Some of the big sewers are also uninhabited, for they carry so much effluent that rats cannot traverse them, and in the biggest London sewers many rats are swept away drowned. Even where the sewer is not very large, if the depth of effluent is as much as one-third of the height of the channel, rats cannot traverse it. Parts of a sewer system may become surcharged at certain times of day, when effluent accumulates faster than it can be removed, so that some sewers afford passage to a rat only during certain periods of the day. Thus in Oxford, the capacity of the engines at the pumping stations was not sufficient to keep pace with the accumulation of effluent in the middle of the day. During the peak flow the sewage in the main outfall 'backed up', giving rise to a surcharge which at its maximum was 14 ft., when all sewers in the system lying less than 14 ft. above the base of the pit at the pumping station were flooded. In some towns the surface water drains overflow into the foul sewers when overloaded after particularly heavy storms.

The nature of the effluent, as well as the amount of it, sometimes appears to account for the absence of rats—as in the vicinity of chemical works, &c., but the greater part of a typical system probably offers them potential cover. The sewer is made big enough to carry the maximum quantity of effluent that it is likely to be called upon to convey, and very often there is only a slight trickle that the rats can easily move through or avoid entirely. As the flow increases the part of the wall above the water line becomes too steep for rats to be able to run straight along it and they progress by zigzagging from side to side.

Available food and cover are the first requisites in an animal's environment. The sewers offer admirable cover to rats so that one would expect the density of the populations to bear a close relation to the amount of food available either in the sewer itself or where the rats have access to it. In fact, the evidence of experimental work and the records of clearance campaigns carried out by local authorities all over England, suggest that the amount of food available in the sewer itself is the chief factor limiting the numbers of the rat population in most otherwise habitable sewer systems. Independent surface water systems are unlikely to harbour rats for they could only exist by leaving the drains to feed, as by raiding food stores in houses, &c. On one occasion in Oxford, bait placed in a surface water drain was eaten by rats; but this observation has not been repeated, although a considerable number of such drains have been baited in other places where the foul and surface water drains are separate. Very few rats were found in the sewers of London Dock, or those of Millwall Dock. These sewers serve for the removal of surface water and waste from a number of workmen's lavatories at various points. The only manholes where bait was taken were near the dock offices where the concentration of people is greatest. Since the food available to rats in sewers is that which humans have wasted, it is generally found, as might be expected, that the distribution and abundance of the sewer rat population is closely related to that of the human population. This relation is discussed in greater detail in a subsequent section, with special reference to the effects of bomb damage.

The physical conditions in sewers, except for the few that carry effluent of a harmful nature, are apparently such as brown rats can readily tolerate. Humidity is always very high and the temperature has a restricted daily range, generally much higher in the sewer in winter, and rather lower in summer, than in the open. It is always dark in the sewers, and altogether conditions show less daily or seasonal variation than in most environments above ground. It would not be surprising, therefore, if the habits of the sewer rat population were found to differ from those of other brown rat populations. A sample of rats from the Liverpool sewers, collected over a period of one year, was compared with a sample from other sources collected in the same period (Perry, 1945) but there was no evidence that the breeding habits of the two samples were different. The pregnancy rate varied with season in the same way in both samples and there was no difference between them as regards litter-size, &c. Of the day-to-day behaviour of rats in sewers, we know very little. We do not yet know, for instance, whether or not their feeding habits differ from those of populations above ground.

It is a notable fact that we have no instance of *R. rattus* living in sewers, although mixed populations of brown and ship rats occur in surface infestations. It may well be that ship rats cannot tolerate the physical conditions of the sewer. If the ship rat sometimes entered the sewer system but failed to establish itself there because of lack of suitable breeding places (or if it were eventually ousted by the other species) one would expect to discover an occasional ship rat. This would be especially likely in a sewer system under heavy surface infestations such as are found in the riverside areas of London, and in Bombay (Turner *et al.*, 1922); but ship rats have not been found in the sewers in these two places or elsewhere.

It would be interesting to be able to form some idea of the number of rats to be expected in a typical sewer system, but it is difficult to arrive at any estimate. The best evidence we have comes from London, in the records of the sewer rat campaign of 1943–4, together with some data obtained during small-scale experiments there. Experiments in the City of London revealed an average take of bait corresponding to about ten rats per manhole in an infested area before the large-scale campaign. Other places were discovered where the sewers harboured no rats at all, while some infestations were undoubtedly far heavier than those in the City. Taking the average number of rats per manhole, for the whole of the area covered by the L.C.C. main drainage system, to be of the order of ten implies a population of about 900 rats per mile of sewer or thirty-five rats per acre. This is a very tentative estimate and it must be remembered that the density of the sewer rat population varies enormously from place to place. The largest single take of bait was 1,500 g., representing 30-60 rats at one manhole.

3. RAT MOVEMENTS

(*a*) Between sewer and surface

The relation of the sewer rat population to surface population has direct bearing on the ecology of the sewer rat and on problems of urban rat control. There is some interchange between sewer and surface infestations but its frequency and importance are difficult to estimate. The larger sewers are inspected at regular intervals and can be kept free of faults, but the greater part of the municipal system is of such construction that breaks permitting rats to enter or leave the sewer may long be undetected. However, there is apparently little traffic of this kind and when sewer rats do invade buildings they usually appear to enter by dried-up interceptors or faults in the household drains. Sometimes a dried-up water closet has been found to be used by rats and there are reports that occasionally a rat will come out through one containing water.

Another type of drain leads from a grating in a basement floor through a U-trap to the main sewers. These gratings may be defective and in basements which are not regularly washed down the water evaporates and may lead to a serious infestation of the property. In any case the interceptor trap is not always a barrier to the rat, one having been seen trying to get through a grating in the floor of a butcher's shop. The animal eventually went away through the water again.

Only one instance of rats getting into a domestic inspection pit has been reported to the Oxford City Engineer (although it is probably a more frequent occurrence, especially where the 'rodding arm' is not properly closed.) This report was confirmed by the presence of fresh droppings; but it was not certain that any interceptor trap had been built into this system.

Thus a number of instances have been recorded of rats regularly passing between buildings and a sewer; but even in these cases there was no apparent reason why the rats should retire to the sewer save that a dried-up drain or other such means of access happened to be there for them. There have been no instances where it could be shown that the rats were forced to depend on the sewer for cover or the surface supply for food. We may assume, then, that such a situation does not occur often enough to present a serious problem. But we are still left with the problem of the sewer populations as a reservoir from which buildings may be invaded—or, more particularly, from which they may be re-invaded after a clearance campaign.

Most evidence about sewers as a source of infestation for premises is circumstantial; but at a certain food shop this probability is very great. Many completely successful clearances were carried out only to be followed by invasion some days or months later, though there were no rat colonies in the adjacent premises (Ch. 4, § 16 (*d*)). During one period of surplus prebaiting inside the shop the three nearest manholes were also baited with large quantities of food. The consumption of this bait in the sewers made no difference to that inside the shop; from which it was only possible to conclude that the rats, if they had come originally from the sewers, were not at the time passing regularly between the two habitats. Eventually, when the sewer rats were also poisoned, the shop remained clear.

There can be no doubt that the rat population of the sewers constitutes a threat to the permanence of any large-scale clearance. Even a low frequency of traffic from sewer to surface would be sufficient to detract seriously from the effectiveness of such a clearance.

(*b*) Movements within the sewers

(1) *Foraging range*. An experiment was made in Oxford by Chitty and Freeman in which rusk coloured with chlorazol blue (Ch. 4, § 3(*c*)) was placed in a central manhole in a section of a system known to be infested. The coloured bait was renewed daily and all the rat dung was swept up each day from all adjacent manholes. Fig. 2 shows the points at which blue-coloured and normal dung were found. Coloured dung appeared progressively at more and more manholes, rising from three (including the baiting manhole) on the first day to seven by the third and fourth days. Uncoloured dung only was found in one manhole, although it was only 60 yds from the bait.

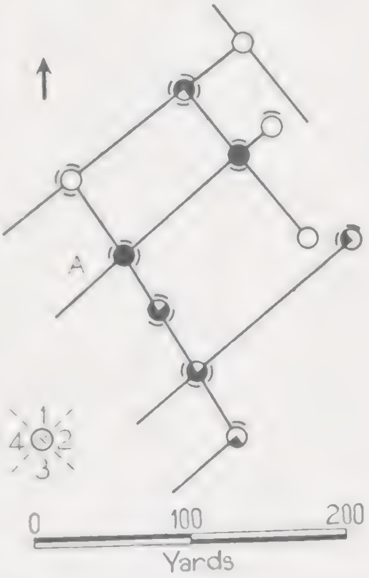


FIG. 2. Distribution of coloured and normal rat droppings in an Oxford sewer system. A surplus of dyed bait was placed each day at manhole *A*. Quarter-circles show results at each manhole on days 1–4: presence of dyed faeces shown by black, normal faeces by segments of outer circles.

It is shown by these results that some rats in this system would travel up to 216 yds. The greatest distance between manholes where there was blue dung, i.e. the greatest length covered by a continuous population, was 372 yds. This distance could not be exceeded because this particular system was mostly bounded by dead ends or, on the south-west, by uninhabitable sewers. That normal dung continued to be found in the manholes showed that not all the rats in the system were feeding at the bait point—either some rats were not moving as far as the baited manhole, or rats were feeding on some days and not on others. This experiment showed that the only safe way to poison a rat population in sewers was to lay bait in every possible manhole.

(ii) *Invasion*. The plan of a 9-in. pipe sewer system at Park End, Bromley, is shown roughly to scale in Fig. 3. Rats were using the larger sewer running through the manhole *A*, but there were no rats in the rest of the section when the experiment was begun. (It is not uncommon to find such a section unoccupied by rats, and although, as in this case, the amount of food in the sewer may only be sufficient for a few rats, there is often no apparent reason why there are no rats at all.) 130 g. dry wheat was placed on the benches at each of the five manholes on 17 February 1944 and was not renewed subsequently. The progress of events is shown in Fig. 3. All the wheat was eaten at *A*, but none at the other points, by 18 February (1st day). By 24 February (7th day) all the wheat had been taken from *B* and *C* and some from *D*. By 29 February (12th day) all had been taken from *D* and some from *E*.

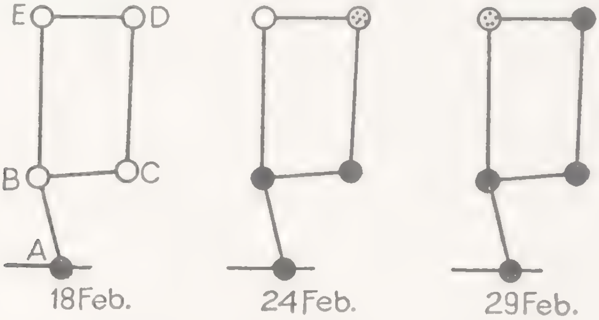


FIG. 3. Extension of foraging range into an unoccupied sewer system in Bromley as shown by disappearance of bait. Complete takes, black; some take, stippled. *A* to *E* is approximately 200 yds.

This quantity of wheat could have been eaten in the time by two rats, if not by one. But in fact it was about 10 days before grain placed at *E* was eaten at all, though *E* is only about 200 yds. from *A*, in the sewer in which rats were living.

Another experiment of a similar kind was carried out in the City of London, in a section of the sewer system near the northern boundary of the City. The buildings in this area had been entirely demolished and the debris cleared, so that the basements were exposed and the sewers ran in some of the partitions of a kind of huge honeycomb. The section comprised nineteen manholes and was connected with the 'live' sewers of the surrounding built-up area at a number of points. 250 g. dry wheat was laid in each manhole on 2 November, but no rats were feeding in the area when the experiment was begun as there was no take by the following day. By 8 November some or all of the wheat had been eaten at seven points, all near the periphery of the area, and within 200 yds. of 'live' sewers. By 15 November there were takes at a further two points. The amount of wheat taken was usually small: by 8 November the 250 g. at each point was partly eaten at three manholes and wholly eaten at four.

These two experiments suggest that a feeding population extends its range by the spasmodic explorations of a few individuals.

(iii) *Re-invasion.* A 1–3–5 day treatment was carried out (19–21–23 Oct. 1943) in a section of sewers between Fleet Street and the Embankment in the City of London. This section connects at four points with the Fleet Street sewers (which also contained rats at the time) but does not connect with other sewers. The poison bait was cleared away on 25 October and postbait was laid. The postbait was nibbled at a few points on the first few days, after which there was no further take. This curious behaviour has not been explained, but it is possible that the wheat was nibbled by young or sick rats that survived the poison baiting for a short time. Fresh wheat was laid on 9 November and by the following day about 20 g. had been taken at one point near the middle of the system. There were no takes elsewhere. A month later, 8 December, fresh wheat was again laid in all the manholes and by the following day 20 g. had again been taken from the same manhole and none from elsewhere. The amount of wheat taken suggests that a single rat had invaded the system in the interval between the first postbaiting and the second (between 30 Oct. and 9 Nov.). The fact that the wheat was taken only at a central manhole suggests that this 'one rat' entered the sewer from nearby buildings and had not moved in from the Fleet Street sewer.

From 13 to 17 December, a few days after the last observation in this experiment, the Corporation baited these manholes with rusk in the course of a general sewer campaign. 'Good' takes were recorded from the central manhole where wheat had been taken in the course of the experiment, and 'small' takes were recorded from two manholes near Fleet Street. This suggests that rats had by this time begun to enter the area from the Fleet Street sewer.

4. BOMB DAMAGE

It has been emphasized in the preceding sections that all the available evidence suggests that rats living in a sewer system depend for the most part on the food they find in the sewer itself, and it has been shown that the sewers in a bombed area of the City of London were not occupied by rats. This area was one in which all the buildings had been demolished, and from which all the debris had been removed. The sewers themselves were big enough to be inspected along their whole length, they had been repaired and the drains had been sealed off where they entered the sewers. The rats that had presumably occupied this sewer system before the bombing had disappeared. Some may have been trapped in the drains where these were sealed off, but the majority probably found their way into the nearby 'live' sewers.

The situation is different when only a proportion of the buildings in a district is damaged and abandoned, while others remain occupied. This was the case in the Isle of Dogs (Poplar), and the situation was such as to afford a clear picture of the relation between bomb damage and the reduction of the human and sewer rat populations. Figs. 4 and 5 show two districts of domestic property in the Isle of Dogs, about half a mile apart, each occupied almost exclusively by houses of the same age and type and each partially surrounded by open spaces. The figures show which houses were still occupied at the time of the survey, and which had been abandoned. It is seen that the damage, which was from high-explosive blast, was distributed haphazard and that there were rows of houses of which some were occupied and others abandoned. The sewer systems of these districts were therefore still carrying waste but in reduced volume. The sewers themselves were damaged and there was an accumulation of silt in some of them. There had been no opportunity for repairs and rats in the sewers must have had increased access to places above ground.

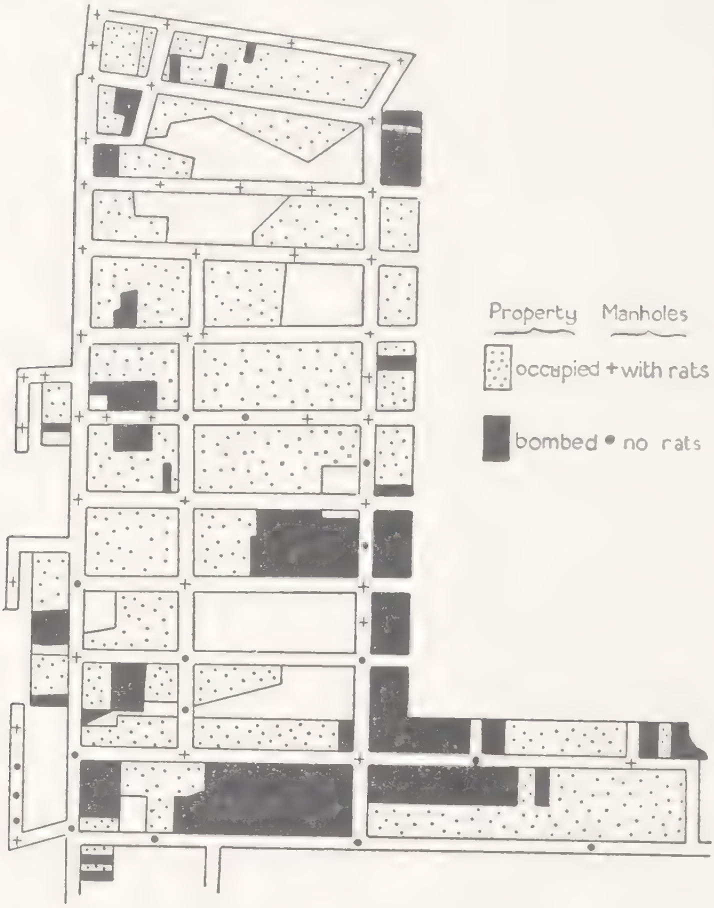


Fig. 4. Area *A*, Millwall. Distribution of bomb damage, occupied houses, and rats in sewer manholes.

This is a kind of situation that was common in many parts of Britain after bombing, and one over which a number of local authorities expressed anxiety lest the rats should get out of broken sewers and invade premises in large numbers. But during the campaign against sewer rats undertaken by London local authorities in December 1943, information was obtained about conditions as they really were. All the manholes in the two districts *A* and *B* are marked to show presence or absence of rats. As the houses were all of a similar size and type, the proportion of occupied houses in each district could be estimated by area as follows:

	District A (*Millwall*)	*District B* (*Cubitt Town*)
Proportion of property occupied (by area) . .	73%	34%
Proportion of manholes where some take was recorded	73%	31%

The exactness of the correspondence between the percentage of 'manholes with rats' and 'houses with people' is of course a coincidence though it emphasizes the main point that the ratio of occupied houses to infested manholes is closely similar in each district.

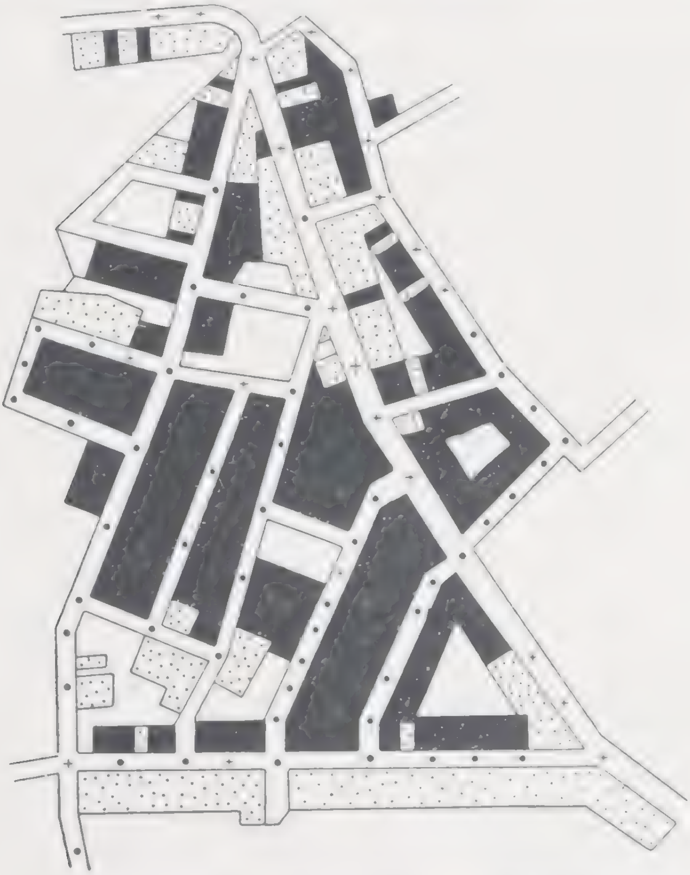


FIG. 5. Area *B*, Cubitt Town. Legend and symbols as in Fig. 4.

The situation in these two districts is known in detail, and the picture is clear because they were occupied by domestic property of one kind, and each of the two districts was more or less isolated from other property housing rats in any numbers. Elsewhere the picture is less clear, but in every case that has been studied, a reduction of the number of people using any system has apparently been followed by a reduction in the number of rats living in it. The situation described above was that existing some months after the bombing, and we do not know the course of events immediately after it. It is possible that the sewer rats left the area by coming to the surface and then dispersing, but it is more likely that they dispersed along the adjoining sewers.

5. POISON BAITING

(*a*) Experiments with direct poisoning

Because of the peculiar nature of the environment, and because competition for food might be supposed to be keen among rats in sewers, there remained the possibility of direct poisoning being effective there, even after it had been shown to be unreliable in other environments. Empirical experiments were therefore undertaken to determine whether the prebaiting period could be reduced or discarded. Considerable data have been collected which show that prebaiting is superior to direct poisoning in sewers just as in surface infestations.

In the descriptions of large-scale control experiments and control measures that follow, the term 'standard treatment' means prebaiting for 4 days, poison bait being laid on the fifth day. This was recommended for control measures in sewers at the time of the experiments. On occasions, however, the 1–3–5 day treatment, recommended for the control of surface infestations, appears to be equally effective against rats in sewers. The 1–3–5 treatment does not, strictly speaking, involve a reduced prebaiting period as compared with a standard treatment and involves no more labour than would be required for prebaiting on two successive days and poisoning on the third. The prebaiting period would have to be reduced to 1 day, or else eliminated, to give a control method involving fewer man-hours than does the 1–3–5 treatment.

In small-scale experiments in Bromley, where the bait was weighed each day as would be done in an experiment above ground, the daily take was found to increase for 4 or 5 days in most cases, but in a few cases it was as high at the first measurement as on subsequent days. Records kept during the sewer rat campaign in Poplar in December 1943 have been analysed and throw some light on this point. During the first treatment, 1,632 manholes were baited each day for 4 days and poison bait was laid on the fifth day. The number of manholes at which some take was recorded on successive days was 570, 651, 677, 761. Takes were recorded as 'small', 'good', or 'complete', and the number of complete takes over these 4 days increased as follows: 315, 415, 421, 476. Some of the increase in the number of manholes at which some take was recorded was probably due to the rats extending their range as the new food supply was discovered; but the increase in the number of complete takes indicates that there was, in general, a build-up in the takes at individual manholes. During census baiting by Mrs. Flatt at Ealing the total takes from forty-one manholes, estimated by the method described below, increased over 5 days as follows: 91, 139, 204, 256, 271 oz. wheat.

Large-scale field tests of direct poisoning, however, were carried out, partly because such empirical experiments are the only means of comparing two control methods in practice, and because direct poisoning would be effective and economical if it could be shown that it gave a kill of, say 75%, not only in an initial treatment but also in a follow-up treatment. If 75% of the residual population of 25% could be killed, the double treatment would have reduced the rats by about 94%.

Three such large-scale field tests have been carried out by the Bureau in co-operation with the M.O.F., and one other was carried out by S. A. Barnett of the M.O.F. alone. One of two done in Reading compared the efficiency of a single direct poisoning with a single standard treatment, the other compared two successive treatments of both methods respectively. In the former, direct poisoning killed only 75% of the rats, in the other, the percentage kill was nearer to that of the standard treatment—90% compared with 94%; but the census baiting, ending too closely before poisoning, may have influenced this result by exercising a prebaiting effect. In view of this possible error and to obtain further evidence, a repeated experiment was planned on modified lines and carried out in Ealing by Mrs. Flatt and the M.O.F.

One further experiment of this type was made at Reading in which a 1–3–5 day treatment was carried out but not compared with a control area. The result was unsatisfactory (80% kill), but it was probably prejudiced by the fact that the poison bait was left in place for only 24 hours. Two days of prebaiting was effective in small-scale operations in Oxford, and as mentioned above, a small section of the City of London sewers was cleared by 1–3–5 treatment. More evidence is desirable and it would be valuable to repeat the Reading test in some suitable place. The reason that this has not been done is simply that these large experiments involve a disproportionate amount of labour and expense.

The Reading experiment in which a single direct poisoning was compared with a standard treatment, and the Ealing experiment in which a 'double treatment' by direct poisoning was compared with two successive standard treatments, merit more detailed description. The plan was similar in each case (the same technique was applied in all these large-scale field tests). First, an area of convenient size was chosen, comprising as many manholes as could be baited with the available labour, which included one or two sewermen together with the Southern Division Squad of the M.O.F.

in each case. Members of the Bureau and the M.O.F. directed the experiments. The areas chosen were reasonably 'isolated' to eliminate re-invasion as far as possible. Each area was then divided into two sectors, so that one could be used as a control in which the standard treatment was applied. The preliminary survey and mapping of the area, carried out by Mr. A. G. Jenson of the M.O.F. was an important part of these experiments. Another necessary preliminary was to loosen each manhole cover so that there would be no delays during baiting.

The first operation in each experiment was that of census baiting. On the first day all manholes were baited with the same quantity of wheat, using the bait depositor. On the second day the take was estimated visually from street level and a known weight added accordingly, the aim being always to provide a surplus so that no visiting rats were unprovided for. After several days' recording (4 days in Reading, 5 in Ealing), the benches were swept clean and a weighed quantity, estimated to be a slight surplus, was laid at each manhole. The take was estimated on the following day and the residues were removed. This method of census is sufficiently accurate, at least on the final day; for if two people estimate the residue at the bottom of a manhole by examining it from street level their estimates are usually found to agree quite closely, at any rate over a number of manholes and especially when the bait has been subjected to only one night's disturbance. The greatest source of error in this method comes from the over-estimation of very small takes, the bait being disturbed, but very little of it eaten. This error is of course greater in the census following a treatment which leaves very few rats than it is in the initial census.

The Reading experiment, comparing direct poisoning with a single standard treatment, proceeded as follows:

	Experimental sector 39 manholes	*Control sector 35 manholes*
24–29 Apr.	Initial census	Initial census
30 Apr.–14 May	Interval	Interval
15 ,,	10 oz. damp sausage-rusk with 5% zinc phosphide laid at each manhole	6 oz. damp sausage-rusk laid at each manhole
16 ,,	Poison bait take estimated in oz.	16–18 May: Each manhole examined daily and the takes recorded as in a routine clearance operation (by visual inspection as Complete, Good, Small, or None). A further 6 oz. bait was laid each day except where there was no take
17 ,,	..	
18 ,,	..	
19 ,,	Each manhole flushed	10 oz. damp sausage-rusk with 5% zinc phosphide laid at all manholes where some take had been recorded
20 ,,	..	Poison bait take estimated
22–27 May	Final census	Final census

The results of this experiment are summarized in Table 1.

TABLE 1. *Comparison of a single direct poisoning with a standard treatment, Reading, 1944*

Estimated take in oz.	*Direct poisoning (No. of manholes)*		*Standard treatment (No. of manholes)*	
	Initial census	*Final census*	*Initial census*	*Final census*
0	10	23	13	27
1–5 . . .	15	14	16	8
6–10 . . .	8	0	3	0
11–15 . . .	3	1	1	0
16–20 . . .	2	1	2	0
> 20 . . .	1	0	0	0
Total no. manholes .	39	39	35	35
Total with some take	29	16	22	8
Total take (oz.) .	224	57	121	10
% infested manholes cleared . .	. .	45	. .	72
% reduction in take.	. .	75	. .	92

The Ealing experiment, comparing two successive treatments by direct poisoning with two after prebaiting proceeded as follows:

Week	
1	Census baiting throughout the area with dry whole wheat to gauge the initial population.
2 and 3	Interval to avoid any prebaiting effect of the census.
4	Direct poison baiting in experimental sector; standard prebaiting and poisoning in control sector. Damp sausage-rusk and 5% zinc phosphide used.
5	Repetition of census baiting in both sectors.
6 and 7	Interval for two reasons (*a*) to be comparable to the recommended procedure for two standard treatments, (*b*) to avoid any prebaiting effect from the second census.
8	Direct poisoning in experimental sector; standard prebaiting and poisoning in control. Bread mash and 10% arsenic used.
9	Repetition of census baiting in both sectors.

The results of this experiment are summarized in Table 2 which shows the proportion of manholes cleared, as well as the proportion by which the population was reduced. The ineffectiveness of a single direct poisoning as compared with a standard treatment is demonstrated in both these experiments. In Reading direct poisoning reduced the population by 75% and cleared 45% of the active manholes. The corresponding figures for the Ealing experiment were 81·5% and 34%. The standard treatment killed 92% of the rats in Reading and 94% in Ealing, and cleared 72% of the 'active' manholes in Reading and 68% in Ealing. Thus the practical consequences were that twice as many manholes required second treatments after direct poisoning as after prebaiting.

The standard treatment was more efficient than direct poisoning when applied to an already reduced population in Ealing—the second or follow-up standard treatment killed 40% of the rats that survived the first treatment, while in the experimental sector the kill at the second direct poisoning was only 26%. Both these figures are underestimates, because of the error, already described, that attends the estimation of small takes. However, the difference between the two figures is probably real; for this error might be more marked in the control sector (where the proportion of small takes was greater) but it certainly could not affect the experimental more than the control sector.

TABLE 2. *Comparison of two consecutive treatments by direct poisoning with two standard treatments, Ealing, 1945*

	Direct poisoning (No. of manholes)			*Standard treatment (No. of manholes)*		
Estimated take in oz.	*Initial census*	*Census after first treatment*	*Census after second treatment*	*Initial census*	*Census after first treatment*	*Census after second treatment*
0 . . .	42	56	61	34	47	49
1–5 . .	18	27	22	7	6	4
6–10 . .	16	. .	. .	7	. .	. .
11–15 . .	4	. .	. .	3	. .	. .
16–20 . .	3	. .	. .	1	. .	. .
> 20 . .	. .	. .	. .	1	. .	. .
Total no. manholes . .	83	83	83	53	53	53
Manholes with some take .	41	27	22	19	6	4
Total take (oz.)	271	50	37	161	10	6
% infested manholes cleared	. .	34	19 **46**	. .	68	33 **79**
% reduction in take . .	. .	81·5	26 **86**	. .	94	40 **96**

Heavy type shows total effect of two treatments.

In a number of instances when poison bait has been laid for 24 hours and some of it taken, it has been thought that a further quantity had been taken subsequently. An attempt to demonstrate this in the experimental sector of the Reading experiment described above was not successful, and when poison bait was laid in a few manholes in Bromley, Kent, and the take measured daily there was no further take after the first day. In Ealing, on the other hand, when the second direct poison bait was put down on a Monday, none appeared to have been taken by Tuesday; but takes were recorded afterwards.

(*b*) Results of standard treatments

Poison baiting campaigns against sewer rats were done by the London local authorities in the winter of 1943–4, under the direction of the M.O.F. Four days' prebaiting was used; but because of labour difficulties the main campaign did not include postbaiting as a measure of the success. Since the second treatment (with barium carbonate in bread mash) followed not long after the first one (with zinc phosphide in rusk), it partly fulfilled the purpose of a postbait measurement for the latter. It seemed very desirable, however, to carry out a final sample postbait with wheat immediately after the second treatment, particularly as barium carbonate had given variable and partly unsuccessful results in prebaiting above ground.

Such postbaiting was done in some of the City of London sewers where two rat control operations had been carried out, the first beginning 12 December 1943, with poisoning 16 December (5% zinc phosphide in rusk), and the second beginning 17 January 1944, with poisoning 21 January (20% barium carbonate in bread mash).

There was some take of rusk at 355 (88%) of the 427 manholes that were baited in the first operation, and some take of bread mash at 180 (42%) of them during the second operation. Comparison of the records of the first and second operations showed that the initial distribution of the rat population was markedly uneven throughout the City, and, in general, the areas where the initial population had been densest were those in which a larger number survived the first poisoning, as shown by the takes of prebait and poison during the second operation. It was decided to select about fifty manholes in which a postbait census could be carried out, and two adjacent areas were chosen where the records of the second operation showed that there had been some take of prebait at a high proportion of the manholes. These two areas, therefore, were not isolated in any way from the remainder of the City, and the fifty-three manholes within them did not constitute a random sample. On the contrary, they included parts of the City where the initial population was known to have been dense and where there was a relatively large number of survivors from the first poisoning operation.

All but two of the manholes selected had been prebaited in the first operation and takes had been recorded at forty-eight of them. The prebait consisted of 6 oz. 1:1 rusk, and amounts eaten on each of the 4 days were recorded as 'complete', 'good' (*c.* 4 oz.), 'slight' (*c.* 2 oz.), or none. These records give a rough idea of the extent of the infestation, and Table 3, by way of example, includes the fourth day's takes of prebait in each operation. In the second treatment 8 oz. bread mash was used and 'good' and 'slight' correspond roughly to takes of 6 oz. and 2 oz. (This treatment included two manholes not previously baited, but in the argument developed below this error is negligible.)

Of the forty-eight manholes where zinc phosphide had been used, fourteen were clear of rats throughout the second prebaiting, a clearance of only 29% as compared with 51% in the City as a whole. Two weeks after the barium carbonate poisoning a dry wheat census was carried out as follows:

2 Feb.	120 g. dry wheat laid at each manhole.
4 ,,	Each point examined. If the wheat had not been eaten at all, it was removed. If it had been partly eaten it was replaced with a fresh lot. In no case was it completely eaten.
5 ,,	The amount of wheat left at each point was weighed.

A similar census was carried out between 22 and 25 March, except that the take was estimated visually because no portable balance was available. 150 g. wheat was all taken at two points and there were slight takes at seven others. The census was repeated between 24 and 27 May. In this case, when the points were examined on 26 May, the wheat had been completely taken at nine of the ten points at which there was some take, and 500 g. was laid at these points. 500 g. was taken at seven of the points by the following day and 200–300 g. at the others.

As shown in Table 3 there was some take of prebait at 36 of the manholes in the sample area during the second (barium carbonate) operation, and some take of wheat at nine of them when a census was made a fortnight later. Seventy-eight per cent. of these manholes, therefore, were cleared of rats. The experience of various sewer operations, including those already quoted, strongly suggests that in such operations the percentage of rats killed is considerably higher than the percentage of manholes that are completely cleared. There is therefore good reason to believe that the clearance of 78% of the manholes in these areas indicates that a considerably higher proportion of the population had been killed; so that in the present instance, within the sample area, the barium carbonate treatment may be said to have been successful.

TABLE 3. *Results of controlling sewer rats by prebaiting and poisoning*

Date (1943–4)	*Operation*	*No. of manholes not baited*	*Takes of prebait on fourth days*				*No. of manholes with rats*
			None	*Slight*	*Good*	*Complete*	
16 Dec.	1st standard	2	4	6	7	34	*48**
20 Jan.	2nd standard	1†	16	29	2	5	*36*
5 Feb.	Dry wheat postbait	0	44	Mean take 36±7 g.			*9*
25 Mar.	,, ,,	0	46	See text			*7*
27 May	,, ,,	0	43	,,			*10*

* Includes one where bait was taken on the first day only.
† No rats present during first treatment.

It is also possible to use these figures to estimate the proportion of manholes throughout the City that had been cleared of rats by the two treatments taken together. For, in the sample areas, 78% of the manholes at which there was some take of bread mash at the second treatment, were cleared. The number of manholes in the whole City with some take of bread mash was 180. 78% of 180 is about 140. There would therefore be about forty manholes where some rats remained, out of 355 at which there was some take of rusk during the first operation. This means that both operations together cleared about 89% of the manholes. The proportion of rats killed will again be higher than this, as argued above.

The sample areas do not, as already stated, comprise a random sample of the City manholes, but it would seem probable that in the less heavily infested areas of the City as a whole, a higher, rather than a lower percentage of the manholes would have been cleared, so that the figure of 89% may itself be a low estimate.

Further information about the rat population of the City sewers is to be obtained by comparing the results of the three census operations. It will be seen that between 5 February and 25 March there was no increase in the number of manholes at which there was evidence of rats. The manholes with rats did not correspond in these census operations; they did not, in fact, happen to correspond in any one case in the first and second census baiting. The area where the rats were most concentrated by the time of the second census, and where they were still most concentrated at the time of the third, was not the most heavily infested area initially.

Some of the amounts taken at individual manholes during the second census operation were larger than any taken at the first. But the outstanding fact shown by these records is that, although by the time of the third census the number of manholes at which there was some take had only increased to ten (19% as compared with an initial 'occupation' of about 96%), the amount of wheat taken at each of these ten manholes had increased substantially. 500 g. was completely taken at seven of them in one day. Some work was done in some of these manholes some time before the Corporation's operations were begun, and bait takes of up to 1,500 g. occurred at some of the manholes. However, at most places censused at this time, takes of the order of 500 g. were recorded, so that the rat population seems to have re-established itself at its initial level in parts of the sewer system, while failing, up to June, to recover at all in other parts.

6. BAIT TRAYS

During the big poisoning campaign against sewer rats under the direction of the M.O.F., Watson and I were co-operating with the staff of the Public Health Department in the Borough of Poplar, and the records kept during the operations in this borough have been analysed as far as possible. Records of this type, where the operators record their estimation of the 'take', are of more value from an administrative than from a scientific point of view, and they are difficult to analyse. But in this case they appeared to provide definite evidence about the use of bait trays designed by Mr. W. H. G. Saunders, Sanitary Inspector of Camberwell. These are metal trays 10 in. × 6 in. issued by the M.O.F., fixed to the wall of the manhole at a convenient height above the effluent, with a piece of thick rope dangling from them to allow the rats to climb up. They are, of course, used only in manholes without benches. They were installed in Poplar only 4–7 days before baiting began, and the percentage at which some take was recorded was much lower where trays were installed than in places where the bait was laid on the benches (Table 4). This difference may have been because rats did not normally frequent manholes where there were no benches; but it will be seen from the results of the second operation 4–6 weeks later that there was no discrepancy between the percentage of baits taken from the two sites.

TABLE 4. *Comparison of takes from benches and trays*

(*a*) *First operation*

	Takes from 1,098 benches baited				*Takes from 534 trays baited*			
	*'Some' take**		*Complete takes*		*'Some' take*		*Complete takes*	
Day	*No.*	*% of total baited*	*No.*	*% of 'some' take*	*No.*	*% of total baited*	*No.*	*% of 'some' take*
1	441	40·2	306	69·4	129	24·2	52	40·3
2	514	46·8	392	76·2	137	25·7	70	51·1
3	526	47·9	387	73·6	151	28·3	83	54·9
4	583	53·1	427	71·2	178	33·3	92	51·7

(*b*) *Second operation*

	Takes from 1,102 benches baited				*Takes from 523 trays baited*			
1	110	9·9	22	20·0	66	12·6	12	18·2
2	123	11·1	19	15·4	57	10·9	5	8·8
3	134	12·2	23	17·1	67	12·8	5	6·5
4	131	11·9	25	19·1	54	10·3	4	7·4

* 'Some' take = all manholes with rats present.

By comparing the proportion of complete takes from places where rats were definitely present ('some' take) it is seen that in both treatments there was apparently a lower abundance of rats where there were no benches. It should therefore have been possible to clear these sites more efficiently in the first treatment. However, although no figures are available for the relative number of rats killed, it is seen that fewer manholes were cleared (roughly half the proportion) where trays had newly been installed than where the baits had been laid on the benches. These facts suggest that the rats were shy of the trays at the time of the first treatment, a few days after their installation, and had become accustomed to them by the time of the second treatment. This would be in accordance with other experience, for 'new object reaction' has been shown to be exhibited by sewer rats at least as markedly as by rats in other environments (Ch. 5).

7. SUMMARY

1. Sewers provide extensive and largely inaccessible harbourage for the brown rat; but it proved possible to study various aspects of the problem by baiting at the manholes. A quick method of baiting from street level was devised using a 'bait depositor' lowered on a cord.

2. Where the sewers are otherwise suitable for rats, considerable abundance may be reached if there is sufficient waste food.

3. Sewer rats are a potential source of infestation for buildings. Daily movement of 100–200 yds. occur within the system. Vacant territory appears to be occupied only gradually, through the extension of individual ranges.

4. In bombed areas the density of the sewer rat population was related to the proportion of houses still occupied by human beings.

5. The general principles in the control of surface infestations were found to apply to sewer rats, which were not satisfactorily killed by direct poisoning. Objects newly introduced into the environment are apparently avoided by sewer rats.

REFERENCES

BARNETT, S. A. (1947). 'Rodent control in towns.' Ann. Appl. Biol. 34: 297–303.

MINISTRY OF FOOD (1946). 'Infestation control: rats and mice.' 36 pp. London.

PERRY, J. S. (1945). 'The reproduction of the wild brown rat (*Rattus norvegicus* Erxleben).' Proc. Zool. Soc. Lond. 115: 19–46.

TURNER, J. A., GOLDSMITH, B. K., & others (1922). 'Sanitation in India.' 1,133 pp. Bombay.

WHITE, W. H. (1877). 'The main drainage of Oxford. Read before the Ashmolean Society, Monday, 14 May 1877. 5 plates, 23 pp. Oxford.

WHITE, W. H. (1902). 'Extracts from papers on the Oxford main drainage and other works, read before the Association of Municipal Engineers when visiting Oxford in 1876 and 1883.' 24 pp. Oxford.

13

CONTROL OF THE SHIP RAT (*RATTUS RATTUS*) IN LONDON

By J. S. WATSON

1. INTRODUCTION

BEFORE the middle of the eighteenth century the black rat was the common rat in rural as well as urban areas of England, but it is now for all practical purposes confined to ports and to large towns with easy access to ports. Its gradual disappearance from most of the country since the introduction of the brown rat suggests that the former species cannot compete with the latter in most British environments. But in ports the black rat seems able to hold its own (Matheson, 1939). Two factors may account for this; in the first place the black rat is the common rat on ships, and many of the vessels reaching this country are infested. These ships are usually fumigated, but not before the cargo has been unloaded, so that rats have plenty of opportunity to get ashore. Thus the shore population is continuously being reinforced by immigrants. In the second place dock buildings, wharves, many-storied warehouses, granaries, and mills probably provide one environment where the black rat can avoid competition with the brown. *R. rattus* usually nests within the framework of buildings, in hollow walls, or inside stacks or cases of goods; *R. norvegicus* as a rule nests in burrows in the earth either outside buildings or in cellars and similar places. Thus the competition between the two species is to some extent mitigated. As is only to be expected, there is a considerable overlap in the places infested by these two rodents. Morgan, Fisher, and Watson (1942) show that in the second half of 1941, of seventy-four premises in the London docks infested by rats, thirty-six or 49% were infested by both species of rat. The overlap may not in fact be quite as big as these figures suggest, since in some buildings the brown rats were confined to the basement while the black rats were living some floors above; nevertheless, in most of these places both species were caught on the same floor. The figures also show that *R. rattus* is the predominant species, 35% of the places contained only black rats while brown alone were present in 16%. Rodent control at that time was largely by trapping and of 1,020 rats destroyed, 829 or 81·3% were *R. rattus* and 191 or 18·7% were *R. norvegicus*. While these figures should not be taken as representing the actual proportions of the two species in the Port area (because of a possibly differential response by the two species to trapping), the error is unlikely to be very big, and the figures may be considered as approximately correct. Thus rat control in port areas is mainly concerned with *R. rattus*.

2. BAITING METHODS

Experimental work on poisoning methods for *R. rattus* was done for the most part in the area of the Port of London, with the cordial co-operation of Dr. M. T. Morgan, Medical Officer of Health of the P.L.H.A. and his staff, and in various places in London riverside boroughs (Ch. 1, § 8). Experiments were done by Fisher, Perry, and myself and many were also done by the staff of the P.L.H.A. in the course of their rodent control work without direct supervision by members of the Bureau.

Surplus prebaiting and poisoning in containers, the method which was giving good results with *R. norvegicus* elsewhere, was tried out on *R. rattus*. The black rat can be just as easily conditioned to feed from bait containers, P3s, or pipes as can the brown rat. Once the rats are accustomed to the containers they will feed readily from them. Rats took the dry wheat in P3s in a grain silo even though the same food was available outside, showing that some preferred to feed under the cover of such bait boxes rather than in the open. Seven experiments, all highly successful, were done in P3s. The type of habitat frequented by *R. rattus*, dock sheds, food stores, factories, and the like are well suited to the use of containers. The rats live in hollow walls or under other cover and come out to feed often elsewhere. Thus containers can frequently be placed in the ideal position to intercept the rats between their living quarters and their food.

In most of the control work in the docks involving the use of bait containers the standard procedure was adopted of leaving the baited P3s down for 2 or 3 weeks before starting surplus baiting. Thus in only three experiments were the periods between the laying of the containers and the first entry of the rats at all accurately measured; in these three cases it was 2, 8–11, and 14 days respectively. These figures may give an exaggerated picture of this lag period. It is probably quite usual for black rats to enter containers as soon as they are laid. This was certainly so in Palestine where drain pipes were used to hold census bait in farm buildings; and a notable difference was found in Khartoum between the response of *R. rattus* and *R. norvegicus* to petrol tins used as bait containers (Ch. 14). Doty (1945) records that the rats, mostly *R. rattus*, on the sugar-cane fields of Hawaii were feeding confidently from bait containers by the fourth day after they had been placed. Nevertheless, for practical purposes the containers should be left down for 2 weeks before use, both in order to allow for the occasional instances where lag occurs and also to allow time to accustom all the rats in the neighbourhood to feed from the containers.

Since *R. rattus* in England inhabits dock buildings, warehouses, and the like where other animals except cats do not normally occur, the baits can usually be laid with complete safety on the surface. This gives very much quicker results, as the baits are usually eaten on the first or second night and the peak take is reached on the fifth or sixth.

Token prebaiting, which had been found to work very satisfactorily with the brown rat, was adopted for routine control measures in the dock areas after the success of a large-scale rat clearance carried out at a large electrical equipment manufactory. Small metal cups holding 30 g. damp sausage-rusk were used by the rodent officers to measure out a standard token bait. The number of prebaits partly and completely eaten each day compared with the amount of postbait taken, together with trace tests with white powder patches, and search for fresh droppings before and after poisoning gave a clear indication of the results achieved. Out of thirteen tests three were failures. In two of the latter cases prebaiting was done for only 2 consecutive days before poisoning, and although one other test was done the same way and apparently succeeded the two failures suggest that the prebait period should be longer to ensure consistently satisfactory results.

The original method of continuous prebaiting was later modified to the 1–3–5 day baiting system which had become the standard treatment for outdoor infestations of *R. norvegicus*. Small surface baits, 30–50 g. each, were laid and left down for 2 days; they were renewed on the third day and left for another 2 days; the poison bait was laid on the fifth day and again left for 2 days. At least twice as much bait was used on the poisoning night as was used for prebaiting. It was always possible that the small poison baits might not be enough to treat all the rats in a large or dense black rat population, but in practice no difficulty was encountered. The size and number of baits laid must always depend on the individual infestation and can only be decided by the experience of the operator; in any case the population should be so reduced that no difficulties would be presented for a follow-up treatment.

The 1–3–5 day token baiting method was found to work as well for indoor colonies of *R. rattus* as for outside colonies of *R. norvegicus*. It was tried on infestations in a metal working factory (8 tests), in a chemical factory (1 test), in canteens (2 tests) and in a warehouse containing bulk sugar (1 test). Only one of these experiments failed, because the extent of the infestation was not realized and part of it was not treated. This method has a considerable practical advantage over 5 days' continuous prebaiting, especially for urban rat work necessitating block control as it enables twice the area to be covered in a week by reducing the labour by half. It was used exclusively in all the subsequent experiments in Palestine on *R. rattus*.

3. BAITS AND POISONS

The first tests done with dry whole wheat showed that the rats readily ate this bait base. Two small populations were successfully poisoned when 5% fine arsenic was added, but it was difficult to ensure that sufficient poison stuck to the surface of the dry grain. An attempt was made to overcome this by using ground-nut oil as an adhesive. The two tests where the oil was added to the dry grain for the first time with the poison were both failures, though other factors besides the addition of the nut oil may have been responsible for the failure in one of these tests. In three other tests the oil was added to the wheat during the prebait period; two of them appear to have been successful though the poison was not eaten until the second and third day after it was laid. The third experiment failed at the first attempt but all the rats were killed when the same treatment was repeated 12 days later. This rather peculiar result may have been due to a moving population; it is possible that the first attempt may have succeeded and the result been obscured by fresh rats moving in.

Another method of making sufficient poison adhere to the wheat was to increase the surface of the grain by kibbling. Kibbled wheat was used in two experiments in warehouses, one containing various foodstuffs, the other spices. Ten per cent. fine arsenic was used as poison and 95% and 97% of the rats were killed (peak takes of census prebait were 160 and 425 g. respectively).

Wholemeal flour with 10% castor sugar, a standard bait for the brown rat, was tried in one experiment on the black rat with 15% refined Canadian arsenic (peak take 130 g.) and resulted in a 100% kill. In another experiment, with forty bait points, this bait and poison were used in a follow-up treatment on the survivors from a zinc phosphide poisoning in a large food manufactory: all but 8 of the infested points were cleared of the rats but the percentage kill was not determined; it was probably greater than 80%. These two tests suggest that sugar-meal and arsenic may be as effective for black rats as for brown.

These experiments on dry baits, though inadequate in number, seem to show that such baits are quite suitable for use on *R. rattus*. The tests with nut oil are interesting when compared with those on *R. norvegicus*. There is little to suggest that the combination of oil and arsenic is as unpalatable to *R. rattus* as it appears to be to *R. norvegicus* (p. 229). The tests where oil was used throughout the prebaiting period were all apparently successful.

The advantages of a moist over a dry bait for rodent control have been dealt with in Chapters 4 and 7. Brown rats eat more of a wet bait than they would eat of a dry bait and can thereby be induced to eat a larger quantity of the poison than if it were mixed in a dry base. Adding water to a bait probably increases its attractiveness, particularly in warehouses where supplies of water are often limited.

Sausage-rusk mixed with water was found to be a very suitable bait. When used for the black rat it was usually mixed with its own volume of water (i.e. twice its own weight) but it was also found satisfactory when mixed in equal quantities by weight. Moist rusk was adopted as the standard bait base for black rat control in the London docks. When used with either

5% zinc phosphide or 15% refined Canadian arsenic it generally gave satisfactory results wherever it was used (Tables 1 and 2): in food-storage warehouses (11 tests), factory premises (9 tests), and dock sheds (9 tests). Insufficient prebaiting, as already explained, accounts for three out of the only four failures; the other has no obvious explanation.

TABLE 1. *No. of tests* (*on* R. Rattus) *showing takes of postbait after prebaiting and poisoning* (*using 1:1 or 2:1 rusk*)

System:	*Continuous token baiting (generally for 5 days)*			*1-3-5 day baiting*		
Poison:	*5% zinc phosphide**			*5% zinc phosphide*	*10% arsenic*	
Postbait take:	*None*	*Slight*	*Much*	*None*	*None*	*Much*
No. of baiting points						
3–5 . .	2*	..	1	..	1	..
6–10 . .	7*	1	..	2	2	..
11–15 . .	..	..	1	1	2	1
16–20 . .	..	..	..	..	3	..
83 . .	..	..	1	..	..	..
Total . .	..	13	..	3	9	
Type of post-bait	Dry wheat (3 tests), soaked wheat (9 tests), trace patches (1 test)			Dry wheat	Sugar-meal	

* In two small tests 10% arsenic was used in rusk.

TABLE 2. *Surplus baiting tests with 5% zinc phosphide in 2:1 rusk* (*not in containers*)

Peak take of 2:1 rusk	*Take of postbait*
225	0 g. kibbled wheat for 8 days
760	0 g. soaked ,, 14 ,,
85	0 g. ,, ,, 13 ,,
150	0 g. ,, ,, 10 ,,

Zinc phosphide at 5 per cent. was used in a large number of experiments in various environments with moist rusk and usually destroyed a very high percentage of the rats. They took it readily and did not appear to be deterred by the strong smell of phosphine given off when this poison is mixed with a wet bait; indeed it is possible that it may even be attractive, since food such as stored garlic and chillies is attacked by black rats with the greatest avidity.

The fine particle arsenic available in 1941 appears from the preliminary tests mentioned above to have been quite effective against black rats. The refined Canadian arsenic of medium particle size, which became the standard later on, was tested in a number of experiments in London, two tests with sugar-meal already mentioned, two after token baiting with rusk, and nine in alternate day baiting in parts of a factory (Table 1). They indicate that it is a satisfactory poison, a conclusion confirmed by the work with this poison in the Middle East (Ch. 14).

S.A.L.A.M. red squill powder was tried in two tests in dock sheds, in both cases at 10% in 2:1 rusk after surplus prebaiting (peak takes: 270 and 480 g. rusk). Both experiments gave very unsatisfactory results as not more than half of the rat populations were destroyed. Although two tests are not enough to prove it, they suggest that red squill is not suitable for poisoning black rats, a similar conclusion to that reached in the case of alpha-naphthylthiourea (Ch. 2). Doty's work (1945) on the same species in Hawaii showed that red squill was not satisfactory there either; but he and other workers have generally used it in a dry bait only.

4. A LARGE-SCALE TEST OF TOKEN BAITING

Token baiting was first tried out on a large scale against *R. rattus* in an electrical and armaments factory on the south side of the Thames, in London. The factory occupies about forty acres, employs some 3,000 workers and consists of many open and closed sheds and eight large buildings of five to seven stories, in which are workshops and stores.

The rat-borne mite *Liponyssus bacoti* Hirst was present and was causing considerable inconvenience and annoyance in the factory. The mites bit many workers, raising unpleasant weals on their arms and other parts of their bodies. An inspection of the factory showed that both species of rat were present but that *R. rattus* was the more abundant. This species was nesting in racks of stores, and within double walls and ceilings. It was often found that the mites had crawled from such nests to attack workers in the vicinity.

TABLE 3. *Control of* R. rattus *in an electrical factory*

(*No. of infestations observed after initial treatment by prebaiting and poisoning with moist rusk and 5% zinc phosphide*)

Kind of postbait	First postbait		No. retreated with		Second postbait		
	No take	Some take	Zinc phosphide	Arsenic	No take	Some take	Not tested
Moist rusk	9	12	4	12	3	2*	..
Soaked wheat	13†	6			8	0	..
Total	22	18	16‡		11	2	3
	40						

* One of these failures occurred after arsenic, one after zinc phosphide.

† Dry wheat in one test.

‡ Two of the eighteen infestations treated by trapping only.

It was difficult to discover what the rats were eating in the various parts of the factory. Waxes and fats were dealt with in large quantities but there was no evidence that the rats ate or damaged the waxes, and little that they ate the fats. They did, however, do widespread and sometimes serious damage: on one occasion the telephone connexion to a quarter of the factory was put out of action for 4 days by a rat which gnawed through the insulation of a cable. Almost certainly the main food supply came from the workers themselves. They were known to bring in sandwiches to their benches (contrary to the regulations) and throw morsels of food, crusts, apple cores, &c., under their benches and out of the windows. The canteens during the earlier part of the operations described were untidy and refuse was not disposed of promptly. The rats may have lived entirely on food scraps and canteen refuse.

The poisoning treatments of a rat control servicing company and the efforts of the factory people themselves to trap out the rats were alike unsuccessful in ending the mite trouble. In August 1942 Dr. M. T. Morgan was approached by the company with a view to tackling the rodent and particularly the mite problem. He, Fisher, and I inspected the factory, and eventually the P.L.H.A. agreed, with the consent of the M.O.H. of the area in which the factory is situated, to undertake for a period of at least one year the clearance of the rodent population. The work was begun immediately under Dr. Morgan's general direction and with the advice and collaboration of Fisher.

The company at first objected to the use of poison because it might increase the trouble from the mites, since they would probably leave rats dying near the work benches and bite the factory girls. However, it was pointed out that the quickest way to cure the mite problem was to exterminate the rats, and the most efficient way of doing this was by prebaiting and poisoning. It was eventually thought worth while risking a possible temporary aggravation of the mite trouble in order to attain a final permanent solution.

The work was carried out by R. Clifford, Sanitary Inspector, and C. W. Moody, Rodent Officer, of the P.L.H.A. with Fisher. Baiting started on 17 December 1942 on a small experimental scale. Trapping, which hitherto had been the main method of control, was discontinued in all places where baiting was being done. By mid-January 1943 poisoning had been extended and amounted to control measures for the whole factory. By the end of March the poison campaign had achieved considerable success.

Baiting was done by the surface token method described above. Thirty-gramme baits of moist rusk or soaked wheat measured from a standard container were laid for several consecutive days and were followed by poisoning in the same base with 5% zinc phosphide or 15% refined Canadian arsenic. The baits were recorded each day as being completely, ¾, ½, or ¼ taken; postbaiting showed which places required further treatment.

There were forty first treatments all done with rusk and 5% zinc phosphide. These were followed by postbaiting with token baits of rusk (21 tests), soaked wheat (18 tests), and dry wheat (1 test). An objection might be raised against the use of rusk as a postbait after poisoning in the same base since the rats might have developed base-shyness. If this were so, one might expect that the tests where rusk was used as a postbait would appear to have been more successful (because no postbait was taken) than those where wheat was used; but in fact twelve out of the twenty-one tests postbaited with rusk showed survivors, while only six out of the nineteen postbaited with wheat showed survivors. Thus there does not seem to be any evidence of base-shyness, but it is probably not justifiable to use the postbait takes other than as an indication of the need for a further treatment. The absence of any fresh rat traces in the places where no postbait was taken tended to confirm that all the rats had been killed.

The places where some rats remained were again treated, in three cases with rusk and zinc phosphide, in nine cases with rusk and refined Canadian arsenic; soaked wheat was used in three cases with 15% arsenic and one test with 5% zinc phosphide. Trapping was used in the two remaining places to remove the few surviving rats (Table 1).

By the end of March, when the first part of the work ended, there were a few black rats left in four or possibly seven out of the forty places known to have been infested at the end of January. At the end of July the works were surveyed in detail with test baits and searches for signs of rats, and the workers were questioned; ten premises were found to have become infested (mainly reinfested) with *R. rattus*. The factory was in a badly rat-infested district and air-raid damage had particularly exposed it to reinfestation. The factory was never completely cleared of rats, though they were never again a serious nuisance. Subsequent control work was largely a matter of continuous inspection in order to detect rats which had come in from outside, so that they could be dealt with. The factory people were taught how to carry on this work for themselves.

There was no trouble in the factory from *Liponyssus bacoti* during the initial control work as had been feared. One worker was bitten by mites about the end of March; some mites identified as this species by Mr. E. Browning of the British Museum (Natural History) were found on dead *R. rattus* from the factory on 5 April. This was the last record of the mite from this place and no further trouble occurred here.

The work of clearing the factory occupied three men for approximately two months. Fisher was of the opinion at that time that with the experience gained the same work if repeated would require half that labour; an even greater reduction could be effected today by using the alternate day baiting system.

The same method was then applied to the London docks after the good results attained in this factory; they proved equally satisfactory there, as exemplified by the tests already discussed (see also Morgan, Fisher, and Watson, 1943). Rat populations over the whole dock area were reduced to negligible proportions by token baiting and poisoning.

5. MAINTENANCE OF RAT CONTROL

The big problem both in the factory and the docks was then to find the best and most economical method of keeping the rat population down to this level. Both places lay in the middle of heavily rat infested districts and there was a continuous movement of rats into the cleared areas. Rat-proofing, particularly in the factory, provided a partial solution, but even under normal peace-time conditions rat-proofing by itself will not keep buildings clear. Dock warehouses of the most modern rat-proof construction were periodically infested by rats coming in with the merchandise. Under war conditions constructional materials were difficult to obtain and the occasional aerial bombardments made rat-proofing at best a rather temporary measure. A system of regular inspections was therefore instituted, test baits and trace patches being used to indicate the presence of new rats. The work requires a very high degree of conscientiousness consisting as it largely does of the examination of negative evidence, especially if continued by one man for any length of time. In practice it is unlikely that all incoming rats will be spotted immediately. This is probably no very serious matter so long as the organization for dealing with them is in existence. An area that has been cleared of rats will never remain completely free for very long if there are rats in the surrounding districts. The number which will be present at any one time depends almost entirely on the individual worker concerned.

6. SUMMARY AND CONCLUSIONS

1. *R. rattus* proved amenable to the same control methods as *R. norvegicus*. Prebaiting and poisoning in containers, or on the surface with token baiting on alternate days have been found effective. The same bait bases seem to work equally well for both species.

2. Zinc phosphide and arsenic are efficient poisons. There is evidence that the black rat is more resistant to some poisons than the brown; the two failures with red squill suggest that this is unsatisfactory for use against the black rat. Thus while the same methods of applying poison can be used for both species, any new poison must be tested out on each separately.

3. The clearance of a mite-infested rat population in a large factory was successfully undertaken by poisoning, and similar large-scale control was achieved throughout the P.L.H.A.

4. Maintenance of rat-free premises is technically possible provided conscientious operators are employed.

REFERENCES

Doty, R. E. (1945). 'Rat control on Hawaiian sugar cane plantations.' Hawaii. Plant. Rec. 49: 71–239.

Matheson, C. (1939). 'A survey of the status of *Rattus rattus* and its subspecies in the seaports of Great Britain and Ireland.' J. Anim. Ecol. 8: 76–93.

Morgan, M. T., Fisher, J., & Watson, J. S. (1942). 'Rodent control in the Port of London.' Medical Officer, 69: 189–91, 197–8, 205–7.

Morgan, M. T., Fisher, J., & Watson, J. S. (1943). 'Rodent control in the area of the Port of London Health Authority.' Medical Officer, 70: 37–38, 45–46.

14

EXPERIMENTS ON RAT CONTROL IN PALESTINE AND THE SUDAN

By J. S. WATSON *and* J. S. PERRY

I. INTRODUCTION

REQUESTS from the Colonies and other British-controlled territories abroad for advice on rat control could, at one time, be met only by supplying information about procedures used in Great Britain, with the proviso that it was not known how far they would be applicable to local conditions, particularly in warmer climates. The writers were therefore sent to the Middle East in 1945 to carry out experiments, under the auspices of the Colonial Office, who made a grant for expenses.

Palestine was chosen as the main scene of operations, both because widely diverse climatic conditions can be found in areas only a few miles apart, and because facilities for work were readily available. The work was transferred to Khartoum in October because temperatures were no longer high in Palestine except in the Jordan valley, where no further suitable infestations could be found.

Choice tests, designed to discover suitable baits, were carried out at Haifa, and poisoning experiments were done, for the most part, in Jewish agricultural settlements in Palestine. The work was continued in Khartoum, most of the experiments there being done in stores and warehouses.

Rattus rattus is the common rat of Palestine. *R. norvegicus* appears to be confined to the larger coastal towns and was encountered in our experiments at Haifa only (in 5 out of 16 colonies, 4 of which contained both species). Of nine places studied in Khartoum six were infested by *R. rattus* and three by *R. norvegicus*.

The present paper is concerned mainly with baiting and poisoning under warm and moderately dry conditions. Baiting under warm, humid conditions has been largely covered by the work of Doty (1945) in the sugar-cane plantations of Hawaii. Dry rolled oats were found by him to be a particularly satisfactory bait base, care being taken to dry the oats thoroughly before use in order to discourage the growth of moulds. Zinc phosphide suspended in oil was used as poison. Harrison and Woodvile (1948) have found boiled rice a satisfactory base for use with barium carbonate in Rangoon.

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nessey, Deputy Director of Public Health, and Dr. Mishelani, Senior Medical Officer of Haifa; and in the Sudan by members of the Sudan Department of Agriculture and the Sudan Medical Service, in particular by K. L. Lea Wilson of the Department of Agriculture, and Dr. A. E. Lorenzen, Director of Public Health, Dr. N. L. Corkhill, Medical Officer of Health, Khartoum, and A. M. Burrell, Senior Public Health Inspector, Khartoum.

2. EXPERIMENTS

(*a*) Description of localities

(i) *Haifa and district*

Preliminary tests to select a number of baits to be used in poisoning experiments were carried out in Haifa. Some poisoning experiments were also done here and at Attlit, some 12 miles down the coast, south of Haifa. The preliminary choice tests were made in March; poisoning experiments in this locality and a second series of choice tests were made in September.

Most of the places used in Haifa were bonded warehouses, stores consisting of a single room at ground level, made of stone or concrete and with roll-shutter doors. The contents included cereals, flour, beans, sugar, &c. Two large new corrugated iron transit sheds (Plate 8 (*a*)) were used for poisoning experiments in September.

March 1945 was a rainy month at Haifa and the fluctuations of temperature and of relative humidity were large. Early in the month temperatures as low as 3° C. were recorded at Acre (near Haifa), the maximum being then about 15° C. By the end of the month the temperature remained above about 9° C., with a daily maximum of about 20° C. The mean daily maximum temperature at Acre in September 1945 was 29·2° C., the mean daily minimum was 19·6° C. The relative humidity averaged 85% at midnight and 60% at midday. There was a considerable amount of rain.

(ii) *Nahalal*

Nahalal is 8 miles from Nazareth, just south of the main Haifa–Nazareth road in the Plain of Esdraelon. It is a Jewish co-operative settlement, comprising seventy-five smallholdings arranged in a circle. Within the circle are the buildings housing the communal concerns of the village—dairy, shop, stores, mill, garage, school, clinic, &c.—together with the houses and gardens of families not directly engaged in agriculture. Each of the seventy-five farmers works a smallholding immediately adjoining his house and also shares in the work of farming the surrounding land, which is farmed on a communal system. Two farms share a concrete cowshed, while each usually has a corrugated iron shed for storing hay, &c., and a chicken house. The present dwellings are concrete bungalows, but most of the original ones of wood are still standing and many are occupied by refugee families.

Rats were present, often in large numbers, especially in the haybarns and cowsheds. There were wind-boxes round the top of the outside of the walls of the cowsheds under the eaves. This method of ventilation provided the rats with harbourage and good nesting cover. Numbers of pigeons nested in the wind-boxes, usually in cowsheds where there were fewer rats. There were some rats in most of the chicken houses, and a few in the false roofs of many of the wooden bungalows.

Experiments in Nahalal extended from 25 May to 16 June. The mean daily maximum temperature was 30·9° C. in May and June and the mean daily minimum was 16·8° C. in May and 18·6° C. in June. Except for a sharp thunder storm, accompanied by strong gusty wind, on 27 May, lasting an hour or two, there was no rain.

(iii) *Afikim and district*

Another series of poisoning experiments was made in three settlements in the Jordan valley, a few miles south of Lake Tiberias. The settlements were Afikim, Ashdot Yaacov, and Menahemiya. The first two are communal settlements, where the communual dining-room, kitchen, &c., together with dwelling rooms, nurseries, and hospital, are grouped together to one side of the central administrative buildings, while the farm buildings and workshops are on the other side. The whole is surrounded by the farm land belonging to the settlement. Plywood is made from eucalyptus logs at Afikim and at Ashdot there is a jam factory.

Most of the farm buildings in these two communal settlements were free from rats. The cattle are housed in big concrete sheds and the other farm buildings are similarly large, and relatively few in number. There was not, as at Nahalal, a multiplicity of small sheds, barns, and cowsheds. The biggest rat colony at Afikim was found in the plywood factory, others were found in a shed used as a slaughterhouse, a small pumping station in the irrigation system, and a wooden shed used as a miscellaneous store. Rats were found in the jam factory at Ashdot and in the stable.

Menahemiya is an 'individual' settlement, a village comprising independent smallholdings with various types of buildings. The older farms have stone buildings and lean-to shacks of corrugated iron. The newer ones have concrete buildings very like those at Nahalal, with one half of the cowshed housing animals while the other half is used as a store or a workshop. Rat dung had accumulated in most of the cowsheds, in wind-boxes, and on the tops of bins, giving the impression of much larger rat populations than were revealed by subsequent baiting. Experiments were made in thirteen farm premises and one large barn in Menahemiya.

This series of experiments was carried out in considerably higher temperatures than those prevailing at Nahalal in May and June. The mean daily maximum for this district in July and August was about 38° C. and the mean daily minimum was about 23° C. The maximum shade temperature recorded in Afikim during this period was 47° C. The relative humidity was similar to that of Nahalal, the absolute humidity being, of course, very much higher.

(iv) *Khartoum*

Experiments were made in Khartoum in November and December. The climate is warm and day temperatures average 35° C. at midday in November, the minimum at night being about 24° C. The temperatures in December are 1–2° C. lower. The relative humidity is low, rarely exceeding 40% at night and dropping to 19% in the day. The town is not heavily infested with rats and from a number of places where census baiting was done nine were selected as suitable for experimental work. These comprised three food stores, a store of motor equipment on the ground floor of a block of offices in the centre of the town, a very untidy cellar, crowded with empty boxes and packing cases under a drug-store (Plate 8 (*b*)), the workshops of the Public Works Department, a railway baggage office, a brick shed holding fodder for mules kept tethered in an adjoining yard, and a mud building holding camel fodder by the camel lines just outside the town.

(*b*) Bait preferences

The baits recommended in Great Britain (M.O.F., 1946) are moist sausage-rusk, sugar-meal, and bread mash. Sausage-rusk is not generally available outside Britain; sugar-meal is a dry bait and it was thought probable that a dry bait would be less effective than a moist one in hot climates. Bread mash is messy and is not suitable for use in large quantities. But it was known that soaked wheat is very readily taken by rats in England and it was decided to concentrate on some widely grown cereals, and use them in a form requiring a minimum of processing.

Wheat, maize, barley, lentils, millet, and rice were tested. In all cases the grain was soaked in water for 12–24 hours before use. Maize and barley were first crushed. This was thought to be advisable in the case of maize because rats presented with the whole grain tend to eat only the germ, and in the case of barley because it has an inedible husk which is removed and left uneaten by the rats, so that a poison adhering to the husk is not eaten. 'Crushed barley' here means barley that has been through the first rollers in the process of milling, so that the grains are crushed but not ground up. 'Crushed maize' means maize treated so that the individual grains are broken into three or four pieces without the corn being reduced to meal.

The relative attractiveness of the six cereal baits named above was tested in Haifa in March 1945 by a series of choice tests in which two baits were offered simultaneously. Further experiments were made in Haifa in

September 1945 in which baiting with one cereal was followed by baiting with another, wheat and barley being compared in this way.

(i) *Choice tests*

The stores and warehouses in which these experiments were made have already been described. The tests all followed the same plan. In each a known quantity of grain was soaked in an excess of water for 12–24 hours. Shortly before use the excess water was drained off and the bait weighed. It was found most convenient to carry the wet bait in a sieve suspended in a bucket; by this means it was easy to obtain a reasonably constant water content in both whole and crushed grain, since any surplus water which might be left in the bait drained through the sieve. Baits were tested in pairs. In the case of wheat and maize, for instance, equal quantities by weight of soaked wheat and of soaked crushed maize were laid side by side at each bait point. The baits were renewed each day and the positions of those at each bait point reversed as a precaution against the results being obscured by a 'place preference' on the part of the rats. There was no evidence of such place preference in any of the tests. Wheat was tested against each of the other five baits and barley and maize were further tested as a pair.

Wheat and crushed maize will each take up about half of their own weight of water in 12–24 hours' soaking, while barley will double in weight. A factor to be taken into account was the loss by evaporation during the 24-hour period over which the bait was left down. It was impossible to determine this exactly, as it was affected by the disturbance of the grain by the rats. A large pile of bait, left undisturbed, would lose relatively less water than would a smaller amount scattered about. But the loss of weight by evaporation was found to be about 10–20% and a figure of 15% has been used in all cases (in Palestine) in calculating how much bait was taken by the rats. Knowing the amount of 'dry' grain that is represented by 100 g. of the soaked bait, and the loss by evaporation in 24 hours, it is possible to calculate, when the residues are weighed, the weight of the soaked bait that has been eaten, and its 'dry' content. The amount of soaked bait that has been taken, referred to here as the 'wet take' is callated thus:

$$\text{Wet take} = W - \frac{100R}{85}$$

where W is the amount of soaked bait laid, and R is the weight of the residue assuming that 100 g. of soaked bait would lose 15 g. by evaporation. Then

$$\text{Dry take} = \left(W - \frac{100R}{85}\right) \times P$$

where P is the proportion of dry grain in the soaked bait.

$$P = \tfrac{2}{3} \text{ for wheat, maize, and millet.}$$
$$\tfrac{1}{2} \text{ for barley.}$$
$$\tfrac{8}{15} \text{ for lentils.}$$
$$\tfrac{3}{4} \text{ for rice.}$$

A number of the tests had to be carried out in places where both species were present. Each series of choice tests was done on some colonies of *R. rattus*. Wheat and maize, wheat and barley, and wheat and lentils were also tested on *R. norvegicus* while wheat and maize, wheat and millet, wheat and rice, and maize and barley were tested in places where both species were present and it was impossible to distinguish between the takes of the two species. The results of the choice tests are summarized in Table 1.

TABLE 1. *Preferences between baits according to total take ('wet') and after correction for added water ('dry')*

*Total amount of one bait taken (g.) and relative amount of the other (heavy type)**

Choice of soaked bait	*No. of tests*			*R. rattus*		*R. norvegicus*		*Mixed colonies*	
	R.r.	*R.n.*	*Mixed*	*Wet*	*Dry*	*Wet*	*Dry*	*Wet*	*Dry*
Wheat Maize	5	1	3	1,830 **0·562**	1,220 **0·562**	750 **0·487**	500 **0·488**	978 **0·533**	653 **0·534**
Wheat Barley	1	1	..	1,106 **0·958**	738 **0·718**	648 **1·407**	424 **1·076**	.. ..	.. ..
Wheat Lentils	2	1	..	2,770 **0·924**	1,850 **0·736**	297 **0·485**	198 **0·379**	.. ..	.. ..
Wheat Millet	4	..	3	1,365 **0·207**	910 **0·208**	.. ..	.. ..	725 **0·448**	484 **0·448**
Wheat Rice	3	..	3	301 **0·276**	200 **0·310**	.. ..	.. ..	858 **0·233**	572 **0·262**
Maize Barley	6	..	2	1,070 **1·358**	714 **1·017**	.. ..	.. ..	230 **1·378**	156 **1·019**

* Tests covered the following number of days: 5 (2 tests); 4 (17); 3 (10); 2 (3); 1 (3).

In the three series, where it is possible to compare the takes of the two rats, there appears to be a marked difference in their relative preference for various baits. *R. norvegicus* seems to prefer soaked crushed barley to soaked wheat while *R. rattus* takes wheat slightly more readily. The comparison of soaked wheat and soaked lentils show that *R. norvegicus* has a marked preference for soaked wheat while there is no very great difference in the amount of each bait eaten by *R. rattus*. *R. norvegicus* has a greater preference for wheat as compared with maize than has *R. rattus*.

It will be seen from the tables that rice and millet were taken in markedly smaller quantities that were the other baits, and therefore no poisoning experiments were made with either of these baits. Lentils, although well taken, were also omitted from subsequent tests because they are much less generally available than wheat, maize, and barley and when soaked are unpleasantly sticky to handle.

From the point of view of poison baiting the wet take is probably more significant than the dry take, and it can be seen that there was not much difference in the wet takes of wheat and crushed barley by *R. rattus*. However, because the soaked barley contained a higher proportion of water, the dry takes of barley by *R. rattus* were consistently less than the dry takes of wheat.

(ii) *Consecutive bait tests*

In the second series of tests in Haifa wheat and barley were compared in a different way. Soaked wheat was used until the daily takes had reached a peak, when soaked crushed barley was substituted and baiting was continued until a peak was again reached. Table 2 shows the peak takes and the sum of the peak takes at four localities for wheat and for barley. In this case it will be noticed that the dry take of barley roughly equals the dry take of wheat, the wet take being correspondingly higher.

TABLE 2. *Peak takes (g.) of soaked wheat and soaked crushed barley offered consecutively* (R. rattus)

	Wet take (g.)	
	Wheat	*Barley*
Warehouse . .	170	180
,, . .	140	220
,, . .	100	160
,, . .	230	270
Total (wet) . .	640	830
,, (dry) . .	425	415

(iii) *Conclusions*

From these results it was decided that three of the cereal baits tested—wheat, crushed maize, and crushed barley—should be used in further experiments. The only real test of the efficiency of a bait base is a series of field poison experiments. We could not for instance conclude, from the fact that the overnight wet takes of barley were bigger than those of wheat, that barley is a better bait than wheat. For a poison bait must be eaten rapidly when the rats first encounter it, and the bait most suitable for poisoning is not necessarily the one eaten in greatest quantity overnight. It is interesting, however, to note that whereas the dry takes of wheat and barley were about equal in the consecutive bait tests (which is in accordance with the results of tests made with caged rats in England) the dry take of wheat exceeded that of barley when both were offered simultaneously. In the first case each bait is tested in competition with the normal food supply, while in the second case the situation is complicated (Ch. 4, § 15 (*c*)). But the purpose of the first series of choice tests was to indicate which baits we should use in field poisoning experiments, and for this purpose they proved adequate. In our subsequent experiments in Palestine and Sudan we used wheat, crushed maize, and crushed barley. The following sections describe these experiments.

(*c*) Initial poisonings

(i) *Methods*

The bait bases tested in poisoning experiments were soaked whole wheat, soaked crushed barley, and soaked crushed maize. All these experiments followed the same pattern. First, a census was taken in the usual way (Ch. 4) with a soaked cereal bait other than the one being tested as a poison bait. In some cases 'complete' and in other cases 'restricted' census baiting was used, depending on whether the census covered the whole or only a proportion of the rat population involved in the poisoning. No evidence was found that a restricted census gave any bias to the results except in the case described below where poisoning also failed to cover the whole of an infested area. The initial census was followed by token baiting on alternate days, prebaiting on the first and third days and poisoning on the fifth. These baits were placed independently from the census points. A second census followed immediately. There was a gap of a few days between the initial census and the prebaiting in most cases, because the initial census took longer in some than in others and it was convenient to wait until all the 1–3–5 day treatments could be started on the same day. In the experiments at Nahalal prebaiting was not begun until a week after the initial census had been completed at all the places. This practice, though desirable on some grounds, was abandoned in subsequent experiments.

Census baiting was usually done at surface points, but drain pipes were used as containers in the cowsheds at Nahalal and other containers were sometimes used elsewhere. It was found that, in general, *R. rattus* entered containers readily but *R. norvegicus*, as in England, showed marked shyness of such new objects in the environment. This contrast in behaviour was clearly demonstrated in one instance in Khartoum. A building by the camel lines in the desert just outside the town was heavily infested by *R. rattus* while a very similar place near the mule lines, some distance away, was infested by *R. norvegicus*. Bait was laid in a tin in each of these places. In the first case, *R. rattus* entered the tin during the first night of its installation, but in the second case where there were only brown rats, the tin was baited for 10 days and had not been entered. On the eleventh day the bait was laid nearby on the surface and was eaten during that night.

(ii) *Results*

The results of poisoning experiments with various baits, using zinc phosphide or arsenic, are summarized in Table 3.

TABLE 3. *Efficiency of first treatments*

	With 5% zinc phosphide			*With 10% arsenic*		
Cereal base	*Places*	*No. of tests*	*% kill*	*Places*	*No. of tests*	*% kill*
Soaked wheat	Nahalal	14	95	Not tried in the Middle East		
	Afikim	4	91			
Soaked crushed barley	Nahalal	9	91	..	..	..
	Afikim	5	78	Afikim	10	90
	Attlit	1	100	Attlit	1	100
Soaked crushed maize	Nahalal	8	92	Haifa	1	< 60
				Khartoum	7	0–80

Soaked wheat and 5% zinc phosphide. Soaked wheat was tested as a poison bait with 5% zinc phosphide in two series of experiments in a wide variety of premises at Nahalal and at Afikim. Fourteen tests were made at Nahalal in June. A complete (100%) kill was obtained in five of them, a kill of more than 90% in six others, and in two, both with small populations, the kill was between 85% and 90%. There was one failure (55% kill) in a store with a few rats and many mice, the mice accounting for some of the bait taken at the second census. The total of the peak takes at the initial bait census in these fourteen experiments was 10,820 g., and the total at the second census was 520 g. Thus the average kill at Nahalal with soaked wheat and 5% zinc phosphide was about 95%. The second series of experiments with this bait was made at Afikim in August to confirm its effectiveness in the more extreme conditions met with in the Jordan valley. Four tests were made. Three of them involved small populations living in a store shed, a small concrete shed housing a pump of the irrigation system, and a wooden shed used as a slaughterhouse. Of these, the first two tests were completely successful but a kill of only 74% was obtained in the slaughterhouse. The fourth test, in the plywood factory, involved a large number of rats. It was a difficult place to work in; the rats lived under piles of timber in various sheds and there was much disturbance in the course of the day. A kill of 90% was obtained in spite of the difficult conditions. The total of the peak takes at the initial census in these four experiments was 1,910 g., and at the second census 180 g. representing a kill of about 91%.

Soaked crushed barley and 5% zinc phosphide. This bait was tested in a series of nine 1–3–5 day treatments at Nahalal. The kill was over 90% in six of the nine, over 85% in a further one, but only 73% and 67% in two others. One of these failures occurred in a barn, more than half filled with hay, where the peak take at the initial census was 1,100 g. Forty bodies were picked up after poisoning but in the second census the daily take rose steadily until the ninth day after poisoning, when 565 g. was taken. Then the barn was completely filled with hay so that further baiting was impossible. It seems likely that this apparent failure was due to re-invasion. Forty bodies was a large number to pick up in view of the available cover, and the smell indicated that there were many bodies not recovered. Rats were discovered in considerable numbers in a nearby chicken house a few days later. They may well have re-invaded the barn from this place after the 1–3–5 day treatment. If this experiment is included in the series the average kill is about 87%. If this experiment is excluded the average kill is about 91%.

A further five experiments with this bait were made in the Afikim district, in the Jordan valley, in August. Four were carried out in farm buildings, the fifth in the storeroom of the jam factory. The percentage kills were 100, 91, 77, 75, and 66. The populations were small so that the survival of one or two rats lowered the percentage kill very markedly. The total of the peak takes at the initial census was 1,120 g. and at the second census 245 g., an average kill of about 78%.

One further experiment with this bait was made in one of the Attlit transit sheds where there were rats living among sacks of grain in large stacks. The peak take at the initial census was 1,260 g. and a complete kill was obtained.

The total of the peak takes at the initial census for all the tests of soaked crushed barley and 5% zinc phosphide was 11,325 g., and at the second census 1,425 g. The average kill was therefore 87%. It is probably justifiable to exclude the experiment in the haybarn at Nahalal when the corresponding totals are 9,225 g. and 860 g., a kill of 91%.

Soaked crushed barley and 10% arsenic. This bait was tested in a series of experiments made in the Afikim district, in the Jordan valley, in August. Each involved only a small rat population and a complete kill was obtained in eight of them. The sum of the peak takes at the initial census was 1,420 g., and at the second census 140 g., a kill of about 90%. In one further experiment in a transit shed at Attlit in September the peak take at the initial census was 700 g. and a complete kill was obtained.

Soaked crushed maize and 5% zinc phosphide. This bait was tested in a series of eight experiments at Nahalal in June. All were on small farm premises like the other experiments at Nahalal. The percentage kill was 90% or over in five of the tests, and between 75% and 80% in the other three. The total of the peak takes at the initial census was 2,570 g. and at the second census 220 g., an average kill of about 92%.

Soaked crushed maize and 10% arsenic. This bait was tested in one experiment in Haifa and seven in Khartoum. The Haifa experiment was carried out in September in a warehouse holding sugar, wheat, and various baled goods, on the first floor of a modern concrete 'rat-proof' building infested with *R. rattus.* The conditions of temperature and humidity prevailing in this warehouse are shown in Table 6, and commented on in § 3. The peak take at the initial census was 2,700 g. The second census had to be discontinued before a peak was reached, but it showed that probably not more than about half of the rats had been killed.

The seven tests of soaked crushed maize and arsenic in Khartoum were made in December, and involved four populations of *R. rattus* and three of *R. norvegicus.* All were failures, none resulting in a kill of more than 80%, while in some there was no evidence that any rats had been killed. No explanation is offered as to why this poison bait should not be successful in practice. Soaked crushed maize with 5% zinc phosphide has been shown to be successful, and soaked crushed maize itself was useful as a census bait. These tests, however, show clearly that soaked crushed maize and arsenic cannot be recommended for control measures.

(*d*) Follow-up treatments

(i) *Soaked crushed barley in Khartoum*

All the experiments carried out in Palestine were designed to show the suitability of various baits in first treatments. It was thought advisable to use available places to get clear results for first treatments before going on to test follow-up sequences. Only in Khartoum was it possible to carry out such a series of second treatments; here soaked crushed barley was used after previous treatments with soaked crushed maize.

As it was not foreseen how completely the first treatments with maize and arsenic would fail, it was thought desirable to ensure the existence of some residual populations by doing two first treatments by direct poisoning. In addition there were five places with surviving rat populations after the previous 1-3-5 day treatments with soaked crushed maize and arsenic. A summary of these seven follow-up treatments using the 1-3-5 day method with soaked crushed barley and 5% zinc phosphide is given in Table 4.

Two of the tests on small populations of black rats in warehouses resulted in the extermination of the rats; but the remaining five tests were all failures, with kills ranging from 72% to 7% of the rat population. The two worst failures were both with colonies of brown rats, though this may have been a coincidence as in both places it was difficult to ensure that all the rats were being prebaited. In both these tests the census was restricted to part of the population; nevertheless (Ch. 4 § 8 (*e*)) it seems safe to regard the results as real failures. For the series of tests as a whole the average kill was 46%.

TABLE 4. *Results of second treatments in Khartoum*

	Peak takes (g.) of soaked wheat	
	Census 2	*Census 3*
	190	0
	65	0
	365*	310
	375*	350
	350	150
	440	125
	100	75
Total . .	1,885	1,010
Av. kill . .	46%	

* Restricted census in colonies of brown rats. Complete census and black rats elsewhere.

This failure is difficult to account for, especially as soaked crushed barley and zinc phosphide had given very good results in first treatments in Palestine. One possibility was that the use of poison in one soaked cereal bait might prejudice the survivors against a subsequent use of another soaked cereal bait. This was a serious possibility since if true it would invalidate the census figures in Palestine. However in a series of tests in England no evidence was found that poisoning in one soaked cereal affected the success of a second baiting with another soaked cereal (see below).

An alternative explanation of the failures is that the climate of Khartoum may have impaired the effectiveness of the baits in some way, though this does not explain the failure of maize, since it did not work in Haifa either. The range of temperature in Khartoum was well within that experienced in Palestine; and although the relative humidity was lower than in Palestine, the saturation deficiency, corresponding to the drying power of the atmosphere was not as high as in some places in Nahalal and the Jordan valley (Table 6). This explanation of the failure does not seem a likely one. It is, however, impossible to reach definite conclusions on the failure with soaked crushed barley in so small a number of experiments, and further speculations would not be profitable. Judging by experience elsewhere it seems unlikely that the baits that gave such satisfactory results in the first treatments in Palestine, would not work when used under the same conditions to follow up a different bait.

(ii) *Soaked cereal baits in England*

As experiments in Khartoum suggested that the use of one soaked cereal bait (soaked crushed maize) with 10% arsenic might have affected the success of a follow-up treatment with another soaked cereal base (soaked crushed barley) with 5% zinc phosphide, it was decided to test in England some of the other bait bases that had been used in the Middle East to find if any such cross-effects really existed in different bait sequences. A series of tests was done on colonies of *R. norvegicus* living in straw-ricks and dyke banks in Lincolnshire.

Technique. Preliminary treatments with direct poisoning were carried out. Every rat-hole was treated with half the usual quantity of poison bait (i.e. a teaspoonful instead of a dessertspoonful) on 2 days, successively or with a day's gap between. It was expected that by putting down small quantities of poison on the first day most of the rats would eat sublethal doses, and that by baiting again on a second day there would be plenty of poison lying about in the holes so that any rats arriving after the first treatment would also have experienced the poison bait before the second treatment was carried out.

First results. About 3 weeks afterwards census baiting with dry grain was done at each of the places previously poisoned. The grain was placed in 3-in. diameter drain pipes set in pairs. It was found that of four places where soaked crushed barley and 5% zinc phosphide had been used, one had been cleared of rats. Of the five places where soaked crushed maize and 5% zinc phosphide had been used, one now contained no rats, and a ditch where another colony had been living had been filled in and the rats had moved. Of the five places where soaked wheat and 5% zinc phosphide had been the first treatment, only one had a residual population of any size left; in the four other places the rats seemed to have been almost completely exterminated, despite the small quantities of poison bait used.

Results of follow-up treatments. Second poisonings were done on the standard 1–3–5 day system and all but one of the seven tests gave good results (Table 5). These tests contradict the possibility suggested by the Khartoum experiments that a poison treatment with one cereal base may prejudice the efficiency of a follow-up treatment with a different poison in another soaked cereal base. The one failure is probably not significant, as occasional failures are to be expected with any type of treatment.

TABLE 5. *Results of second treatments in England*

No. of tests	*Nature of the base*		*Sum of peak takes in first censuses (g. dry wheat)*	*% kill*
	First treatment (with 5% zinc phosphide)	*Second treatment (with 10% arsenic)*		
3	Soaked barley	Soaked wheat	2,010	90*
3	,, maize	,, barley	4,960	90
1	,, wheat	,, ,,	350	100

* Including a kill of 60% of a population which took 370 g. in the first census.

3. CLIMATE

(*a*) General

Two thermohygrographs were used during the investigations in Palestine and the Sudan to record the temperature and relative humidity in representative places where poisoning experiments were being done, and data from regular meteorological stations near the places in which we worked were made available to us by the meteorological services of Palestine and of Khartoum. Published data exist, for Palestine, compiled by Dr. Ashbel (1945 *a*, *b*) of the Hebrew University, Jerusalem. This information is available in the Bureau of Animal Population.

We were concerned with the effect of climate not only upon the rats, but also upon the baits we were using. The baits recommended in the Appendix (p. 518) were effective throughout the range of conditions in which they were tested. Our measurements were of temperature and relative humidity, from which the absolute humidity, the actual amount of water in the air, can be computed and expressed in grammes of water per cubic metre of air. This unit has also been used here to express the saturation deficiency—the amount of water a given sample of air could absorb, without change of temperature, before becoming saturated. The saturation deficiency is especially relevant to a study of conditions in relation to the use of moist baits because it is a measure of the drying power of the air. The absolute humidity and saturation deficiency were calculated with the aid of a nomogram (Baker, 1936).

Table 6 summarizes data for two infestation sites in each of four localities, with similar data from a nearby meteorological station. It will be seen that the minimum figures at the three stations in each locality were not very different. However the range above the minimum of both temperature and drying power of the air differed considerably, as did another feature which is not clearly shown in such a table, namely the number of hours per day of high temperature or low humidity or both. Because of the lag in the recording instruments, these data represent a minimal estimate of the range of temperature and humidity. Conditions often became, for brief periods, more extreme than the recordings indicate.

Standard meteorological records refer to the conditions prevailing inside a Stevenson screen. Rats, however, inhabit a great variety of habitats within any given infested area, and the micro-climates of these habitats may be very diverse. Rats may, for instance, spend all their time in a place with a range of temperature quite different from that experienced in the open or in the environment of other rats not far away. Buxton (1932) showed that conditions in rat burrows in Palestine were much more equable than conditions above ground, and one would expect to find, in a hot country, that rats often contrive to find places to live where the conditions, particularly of temperature, are less extreme than those recorded in a Stevenson screen, and still further divergent from conditions in the open. In fact this is often true, but rats also live and are active in places where the conditions are more extreme than the general conditions for the locality. This was the case, for instance, in Nahalal where rats were trapped in a loft just under the roof of a house. The rats were active in the hottest part

TABLE 6. *Comparison of climatic conditions in various localities*

Place and date	*Temp. ° C.*			*R.H. %**			*S.D. g. per cu. metre*		
	Min.	*Max.*	*Range*	*Min.*	*Max.*	*Range*	*Min.*	*Max.*	*Range*
A. Plain of Esdraelon									
(i) Met. Stn. (Afula), 7 June	17·5	29·0	11·5	40	80	40	5	17	12
(ii) Nahalal haybarn 7–8 June	17·0	42·0	25·0	24	93	69	1	43	42
(iii) Nahalal Mill, 7–8 June	20·0	33·5	13·5	44	87	43	2·5	19	16·5
B. Jordan Valley									
(i) Met. Stn. (Degania), 25 July	20·5	38·0	17·5	64	75	11	7·5	15	6·5
(ii) Afikim onion store, 25–26 July	23·5	38·5	15·0	42	89	47	2·5	25	22·5
(iii) Menahemiya cowshed, 25–26 July	25·0	42·0	17·0	27	75	48	6	41	35
C. Sea Coast									
(i) Met. Stn. (Acre), 28 Sept.	19·0	29·2	10·2	70	90	20	2	6·5	4·5
(ii) Attlit, shed no. 1, 28–29 Sept.	23·0	32·0	11·0	68	90	22	2·5	11	8·5
(iii) Haifa warehouse, 3–4 Oct.	24·0	24·0	0	60	68	8	7	9	2
D. Khartoum									
(i) Met. Stn., 25–26 Nov..	20·0	33·0	13·0	14	26	12	13	30·5	16·5
(ii) Town warehouse, 25–26 Nov.	27·0	29·5	2·5	48	52	4	13	14	1
(iii) Desert hut, 25–26 Nov..	25·0	29·5	4·5	38·5	42	3·5	14	18	4

* The min. and max. temperatures quoted are those recorded by the thermohygrographs but the R.H. was only entered on the record sheets at 3-hourly intervals, and, in the case of the meteorological stations, only at 6, 12, and 18 hours G.M.T. The extremes of moisture and drying power of the air are likely to have been more marked, therefore, than these figures show, especially in the case of the meteorological station readings.

of the day, when the temperature in the loft reached 45° C. (113° F.). Table 6 shows that conditions were also very extreme in a haybarn in Nahalal, where rats were commonly seen twenty or thirty at a time, running about on the beams just below the corrugated iron roof. The thermohygrograph was installed on a beam, away from the walls, about two-thirds of the height from the floor to the ridge of the roof. In this position it recorded temperatures up to 42° C. and the rats evidently preferred an even warmer part of the building. It may be said, then, that we observed no places where the absence of rats could be attributed to conditions of temperature or humidity, when food and cover was available.

(*b*) Temperature

Generally speaking, the Afikim district was considerably warmer than the Nahalal or Haifa districts, and it had a greater daily range of temperature. At the warmest time of day, Khartoum was only slightly warmer than Nahalal or Haifa, and by no means as hot as Afikim, but the fall in temperature in the night was much less in Khartoum than in Palestine.

In places where poisoning experiments were made in Palestine the general differences between Nahalal, Haifa, and Afikim, are masked by differences between various environments within those areas. Thus a haybarn at Nahalal became as hot as a cowshed in Menahemiya in the Jordan valley—the former being a corrugated iron building and the latter a concrete one. Indeed the most extreme temperature ranges quoted were in this haybarn. The ones quoted are not, in fact, the most extreme that were encountered. On one occasion in Afikim, the temperature in a well-ventilated building (of wood) reached 47° C. (117° F.). Conditions were most trying in this area, for the shade temperature often remained over 40° C. (104° F.) for several hours a day, while the humidity made the heat oppressive.

The most marked contrast to the Nahalal haybarn is the warehouse at Haifa where the temperature remained at 24° C. (75° F.) throughout the 24 hours—it did, in fact, remain practically constant throughout the 4 or 5 days during which the thermohygrograph was installed there.

The daily range of temperature was in general less in Khartoum than in Palestine (these data refer to different times of year, their purpose being to describe the conditions in which the poisoning experiments were actually made). The two places in Khartoum that are quoted for comparison with the data from the meteorological station show an even smaller range of temperature than the latter, both being fairly well-insulated buildings.

(*c*) Saturation deficiency

There was a big difference between Khartoum and Palestine with respect to the drying power of the air, for the absolute humidity in Khartoum was so low that even during the night the air retained considerable drying power.

The evaporation in 24 hours was such that 100 g. of soaked wheat would lose 15 g. of water in Palestine (either in the Nahalal haybarn or in the Haifa warehouse), whereas it would lose 20 g. in Khartoum.

The absolute humidity was higher in Afikim than in Nahalal, but the difference in moisture content was, generally speaking, fairly closely balanced by a difference in temperature, so that the saturation deficiency in the Stevenson screen was very similar in the two areas. While the temperature at Haifa and Attlit was similar to that at Nahalal, the absolute humidity was closer to that at Afikim, so that at no time of day was the drying power of the air very great.

The temperature, as has been pointed out, varies very much from place to place in the same district, but the absolute humidity did not vary in this way in the places in which we worked. The saturation deficiency, being a product of these two factors, does vary from place to place within a district, but not very markedly. The effect of such variation upon the amount of water lost by evaporation from a pile of moist bait is completely masked by other factors, particularly by the degree to which the bait is scattered.

Table 6 shows that the saturation deficiency fell to very low levels during the night in Palestine and it was found that, as was to be expected, the evaporation from a bait-pile was very much less during the night than during the day. The loss varies more as between night and day than between two quite different places at the same time of day. In our poison baiting experiments the bait was laid in the morning so that in many instances it probably lay throughout the day before the rats approached it. It was thus shown that it is not necessary, in these conditions, to take the precaution of baiting in the afternoon or evening to ensure success.

4. SUMMARY

1. Preliminary tests were carried out in Haifa in March 1945 to select a number of bait bases to be used in poisoning experiments in the Middle East. Poisoning experiments were made at Nahalal in the plain of Esdraelon in June, in the Afikim district of the Jordan valley in July and August, in Haifa and district in September, and in Khartoum, Sudan, in November and December.

2. All the baits used in the preliminary choice tests in Haifa were tried on colonies of *R. rattus*; three of the baits were tried on *R. norvegicus*, and four baits were also tested on mixed colonies. All the poison tests in Palestine were carried out on *R. rattus*. Six of the places treated in Khartoum contained *R. rattus* and three *R. norvegicus*.

3. The preliminary choice tests showed that *R. rattus* took the baits in the following order of preferences: soaked wheat, soaked crushed barley, soaked lentils, soaked crushed maize, soaked millet, and soaked rice. *R. norvegicus* appeared to have a slightly different order of preference. Soaked wheat, soaked crushed barley, and soaked crushed maize were selected for use in experiments with zinc phosphide and arsenic.

4. The average kills obtained with the poison baits were over 90%, except in the case of soaked crushed maize with arsenic, which killed less than 85% in each of eight trials.

5. One series of follow-up (second) treatments, using soaked crushed barley and 5% zinc phosphide after soaked crushed maize and 10% arsenious oxide, failed in Khartoum. Subsequent experiments in England showed that these failures are unlikely to have been because a poison treatment with one soaked cereal base prejudices the success of a follow-up treatment with a different poison in another soaked cereal base.

6. Records of temperature and relative humidity were obtained in most of the places where poisoning experiments were carried out. Data from representative places are discussed and compared with those from nearby meteorological stations. The most extreme conditions of climate encountered were those in the Jordan valley in August, the shade temperature often reaching the neighbourhood of 40° C. (over 100° F.) with a fairly high humidity. The drying power of the air was greater in Khartoum than in Palestine.

7. There is no evidence that climatic conditions affected the efficiency of the baits recommended in the Appendix in any of the environments where poisoning experiments were carried out. Poisoning was done after 2 days of prebaiting on the 1–3–5 day system.

8. The same baits should prove satisfactory in a range of climate varying from that found in a cool temperate country like England to hot conditions like those encountered in the Jordan valley, with midday shade temperatures averaging 39° C. (102° F.) and a relative humidity of 45%. The baits have not been tried in a hot and very humid climate.

9. Soaked wheat with arsenic was not tested in Palestine; it is very successful in England and there is no reason to suppose it would not be so in the Middle East. Soaked crushed maize with arsenic was a failure.

APPENDIX

DIRECTIONS FOR RAT CONTROL BY POISONING IN HOT AND FAIRLY DRY CLIMATES*

1. *Survey of infestation*

A preliminary survey should be carried out to determine the extent of the area infested by rats and the size of infestations. This area should, as far as possible, be dealt with simultaneously as a unit. Should the labour available be too small to allow this to be done, the area must be split up into blocks of convenient size which can be treated one at a time.

2. *Summary of procedure*

Poisoning is by far the quickest and most efficient method of killing rats, provided it is properly done. It should be possible to kill 85–100% of the rats with one treatment. A poison baiting campaign should be carried out as follows:

(*a*) Estimate from your survey the number of bait points needed and from this the supplies and equipment that will have to be used.

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* The methods here recommended have not been tried out under hot and very humid conditions and may not be found applicable to them.

1-3-5 day baiting

(*b*) Place one dessertspoonful of the plain bait in all occupied holes and other safe places on the first and third days.

(*c*) On the fifth day place one or two spoonfuls of the bait base mixed with poison, using one of the formulae recommended.

Container baiting

(*d*) Where there is danger to humans, animals, or birds, prebaits and poison baits must be placed in boxes or pipes.

(*e*) These containers are placed along rat runs, prebaited and left for 1 or 2 weeks or until rats are using them all.

(*f*) Four dessertspoonfuls of poison bait are given after 5 days of continuous prebaiting.

Follow-up treatment and maintenance

(*g*) It is not possible at the moment to recommend any definite follow-up treatments, but it will probably be worth trying the other poison with a different base to clean up any survivors.

3. *Bait bases*

The following baits are readily eaten by rats in hot, fairly dry climates. The baits are soaked for 12–24 hours and the surplus water is then drained off.

(*a*) Soaked wheat.

(*b*) Soaked crushed barley. This is barley that has been put through coarse rollers so as to crush the grains but not to grind them.

(*c*) Soaked crushed maize. The maize should be crushed so that the individual grains are broken into three or four pieces.

Surplus water can most conveniently be drained off through a sieve. While prebait is being laid the soaked grain can be carried round in a sieve suspended in a bucket so that water collecting in the bottom of the bait can drain away before it is laid. The bait must be left in the sieve till all the surplus water has drained out before the poison is mixed in.

4. *Poisons*

(*a*) Zinc phosphide is used at a strength of 5% by weight in these three baits.

(*b*) Arsenic is used at 10% by weight in soaked wheat and soaked crushed barley. It must *not* be used with soaked crushed maize.

5. *Estimating the amount of bait materials required*

The number of bait points and hence the amount of bait required will depend largely on the size of the rat infestations, determined during the preliminary survey. The amount required for an infestation of a particular size can be learnt only by experience, but it is well to bear in mind that most people tend to underestimate the number of points required. One ounce of soaked grain (about a heaped dessertspoonful) is laid at each point. In order roughly to calculate the amount of dry grain required to yield a given weight when soaked, it should be noted that wheat and crushed maize take up about half their own weight of water while barley takes up about its own weight.

6. *Equipment*

The following items will probably be required: buckets or tins for soaking and mixing the bait; a sieve for draining the soaked grain; scales for weighing out the quantities of grain required, or tins holding known quantities. The poison should be weighed out on smaller (e.g. letter) scales. One or more long-handled spoons are required, consisting of a dessertspoon attached to a 3-ft. rod or stick. When baiting inside buildings a piece of chalk will often be found useful to mark or number the places at which baits are laid so that the same points can be found easily when re-laying the bait.

7. *Poison baits*

The following poison baits should meet ordinary requirements. They are given in parts by weight.

Zinc phosphide	1	Arsenic	1
Soaked wheat or soaked crushed barley or soaked crushed maize	19	Soaked wheat or soaked crushed barley	9

Each of these poison baits must be used only after prebaiting with the same soaked cereal as that with which the poison is mixed.

8. *Placing baits*

Ideally baits should intercept the rats on their way to feed. The best way is to put the bait in all occupied rat-holes. In buildings where it is safe to do so, the bait should be on the floor, on top of walls, &c., wherever there are signs of rats.

Provided a sufficient number of points are baited, one heaped dessertspoonful at each when prebaiting or poisoning should be enough; but two spoonfuls of poison bait should be laid at all points where the prebait has been well eaten. There must always be more poison bait laid than the rats can eat. If it is all eaten it is probable that some rats did not get enough to kill them. Some of the prebait points may be untouched—if, for example, the size of the infestation has been over-estimated; no poison bait need be laid at such points.

The following system will be found very reliable for such baiting: prebait on the first day with plain soaked bait, leave one day gap; prebait on the third day with plain soaked bait at the same points as before, leave one day gap; place poison baits on the fifth day at the same points as before, using the poison in the same base as the prebait.

When this system is used it enables two blocks to be treated during one week; one on Monday, Wednesday, and Friday, and the other on Tuesday, Thursday, and Saturday.

9. *Containers*

Danger to other animals can be considerably reduced by the use of containers for the bait. A box with a 3-in. hole cut in one side or a 15-in. long pipe 3-in. diameter blocked at one end, make convenient containers. Poultry can be excluded by placing a brick or stone 3 in. from the entrance of the container, or by facing the entrance 3 in. from a wall. Black rats enter such containers fairly readily but brown rats are more suspicious of new objects; bait containers should therefore be laid 1 to 2 weeks beforehand. The rats will start to use them more quickly if some dry grain is placed in them. They should be placed beside a rat hole or on a runway. Once the rats have become used to them they will feed readily from them. The containers must be kept on the same spot once the rats have started to feed from them.

As a rule fewer points will be required than if baiting were being done in holes or in the open. Regular prebaiting must start simultaneously in all the containers and should preferably be done for 5 days continuously with poison baiting on the sixth. Four spoonfuls of prebait should be put in each container every day and eight spoonfuls of poison bait on the last day.

10. *Follow-up (second) treatments*

One treatment well carried out should kill 85-100% of the rats. It may however be necessary to carry out a second treatment to deal with the remainder. At the moment it is not possible to recommend a follow-up treatment which is known to work with certainty in hot and fairly dry climates. If, nevertheless, it is thought worth while to use a follow-up treatment, a different soaked cereal from that used for the first treatment should be tried with the other poison. The follow-up treatment should not be done less than a fortnight after the first treatment. It is undesirable to repeat a treatment with the same base and poison with an interval of less than 3 months.

11. *Maintenance of control*

Once the place has been cleared of rats regular inspections should be made so that re-invasions by other rats can be immediately spotted and dealt with. It is a waste of time to leave a place to become badly infested before it is again tackled.

12. *Precautions*

The poisons mentioned here are dangerous if eaten accidentally. However the amount present in small quantities of rat bait is not a serious danger in practice, provided (1) utensils used for mixing and holding baits are cleaned after use and hands are washed, (2) poisons are clearly marked as such and stored in a safe place and unused bait is destroyed, (3) poison baits are laid well inside holes or in other safe places, or at safe times, or else in suitable containers, (4) cats and dogs are shut up or removed or at any rate kept well fed during poisoning to prevent them eating poisoned rats, (5) all accessible remnants or poison bait are trodden into the holes or cleared up and destroyed the day after poisoning.

Moist baits containing zinc phosphide give off small amounts of phosphine gas (which has a strong smell). They must only be mixed in well ventilated rooms, otherwise there is a danger of cumulative poisoning among people constantly exposed to the gas.

REFERENCES

Ashbel, D. (1945*a*). 'Daily temperatures in the Near-East.' 72 pp. Jerusalem. (Mimeographed.) [Hebrew and English.]

Ashbel, D. (1945*b*). 'Temperature and relative humidity in Palestine and surrounding countries.' 86 pp. Jerusalem. (Mimeographed.) [Hebrew and English.]

Baker, J. R. (1936). 'Nomograms for saturation deficiency.' J. Anim. Ecol. 5: 94–96.

Buxton, P. A. (1932). 'The climate in which the rat-flea lives.' Indian J. Med. Res. 20: 281–97.

Doty, R. E. (1945). 'Rat control on Hawaiian sugar cane plantations.' Hawaii. Plant. Rec. 49: 71–239.

Harrison, J. L., & Woodville, H. C. (1948). 'An attempt to control house rats in Rangoon.' Trans. R. Soc. Trop. Med. Hyg. 42: 247–58.

Ministry of Food (1946). 'Infestation control: rats and mice.' 36 pp. London.

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